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ANNUAL REPORT OF THE BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30

1937

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SMITHSONIAN INSTITUTION
WASHINGTON

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(Publication 3451)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1938

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price $1.00 (paper cover)

LETTER OF TRANSMITTAL

Smithsonian Institution,
Washington, December 2, 1937.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1937. I have the honor to be,

Very respectfully, your obedient servant,

C. G. Abbot, *Secretary.*

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ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1937

SUBJECTS

1. Annual report of the Secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1937, with statistics of exchanges, etc., including the proceedings of the meetings of the Board of Regents.

2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1937.

3. General appendix comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1937.

THE SMITHSONIAN INSTITUTION

June 30, 1937

Presiding officer ex officio.—FRANKLIN D. ROOSEVELT, President of the United States.

Chancellor.—CHARLES EVANS HUGHES, Chief Justice of the United States.

Members of the Institution:

FRANKLIN D. ROOSEVELT, President of the United States.
JOHN N. GARNER, Vice President of the United States.
CHARLES EVANS HUGHES, Chief Justice of the United States.
CORDELL HULL, Secretary of State.
HENRY MORGENTHAU, Jr., Secretary of the Treasury.
HENRY HINES WOODRING, Secretary of War.
HOMER S. CUMMINGS, Attorney General.
JAMES A. FARLEY, Postmaster General.
CLAUDE A. SWANSON, Secretary of the Navy.
HAROLD L. ICKES, Secretary of the Interior.
HENRY A. WALLACE, Secretary of Agriculture.
DANIEL C. ROPER, Secretary of Commerce.
FRANCES PERKINS, Secretary of Labor.

Regents of the Institution:

CHARLES EVANS HUGHES, Chief Justice of the United States, Chancellor.
JOHN N. GARNER, Vice President of the United States.
JOSEPH T. ROBINSON, Member of the Senate.
M. M. LOGAN, Member of the Senate.
CHARLES L. MCNARY, Member of the Senate.
T. ALAN GOLDSBOROUGH, Member of the House of Representatives.
CHARLES L. GIFFORD, Member of the House of Representatives.
CLARENCE CANNON, Member of the House of Representatives.
FREDERIC A. DELANO, citizen of Washington, D. C.
JOHN C. MERRIAM, citizen of Washington, D. C.
R. WALTON MOORE, citizen of Virginia.
ROBERT W. BINGHAM, citizen of Kentucky.
AUGUSTUS P. LORING, citizen of Massachusetts.
ROLAND S. MORRIS, citizen of Pennsylvania.

Executive committee.—FREDERIC A. DELANO, JOHN C. MERRIAM, R. WALTON MOORE.

Secretary.—CHARLES G. ABBOT.

Assistant Secretary.—ALEXANDER WETMORE.

Administrative assistant to the Secretary.—HARRY W. DORSEY.

Treasurer.—NICHOLAS W. DORSEY.

Editor.—WEBSTER P. TRUE.

Librarian.—WILLIAM L. CORBIN.

Personnel officer.—HELEN A. OLMSTED.

Property clerk.—JAMES H. HILL.

UNITED STATES NATIONAL MUSEUM

Keeper ex officio.—CHARLES G. ABBOT.
Assistant Secretary (in charge).—ALEXANDER WETMORE.
Associate director—JOHN E. GRAF.

SCIENTIFIC STAFF

DEPARTMENT OF ANTHROPOLOGY:

Frank M. Setzler, acting head curator; W. H. Egberts, chief preparator.

Division of Ethnology: H. W. Krieger, curator; H. B. Collins, Jr., assistant curator; Arthur P. Rice, collaborator.

Section of Musical Instruments: Hugo Worch, custodian.

Section of Ceramics: Samuel W. Woodhouse, collaborator.

Division of Archeology: Neil M. Judd, curator; Waldo R. Wedel, assistant curator; R. G. Paine, aid; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Physical Anthropology: Aleš Hrdlička, curator; Thomas D. Stewart, assistant curator.

Collaborators in anthropology: George Grant MacCurdy; D. I. Bushnell, Jr.

Associate in historic archeology: Cyrus Adler.

DEPARTMENT OF BIOLOGY:

Leonhard Stejneger, head curator; W. L. Brown, chief taxidermist.

Division of Mammals: Gerrit S. Miller, Jr., curator; Remington Kellogg, assistant curator; A. J. Poole, scientific aid; A. Brazier Howell, collaborator.

Division of Birds: Herbert Friedmann, curator; J. H. Riley, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Casey A. Wood, collaborator; Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Leonhard Stejneger, curator; Doris M. Cochran, assistant curator.

Division of Fishes: Leonard P. Schultz, assistant curator; E. D. Reid, aid.

Division of Insects: L. O. Howard, honorary curator; Edward A. Chapin, curator; William Schaus, honorary assistant curator; B. Preston Clark, collaborator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Hemiptera: W. L. McAtee, acting custodian.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: Waldo L. Schmitt, curator; C. R. Shoemaker, assistant curator; James O. Maloney, aid; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; Maynard M. Metcalf, collaborator; J. Percy Moore, collaborator; Joseph A. Cushman, collaborator in Foraminifera; Charles Branch Wilson, collaborator in Copepoda.

Division of Mollusks: Paul Bartsch, curator; Harald A. Rehder, assistant curator; Joseph P. E. Morrison, senior scientific aid; Mary Breen, collaborator.

Section of Helminthological Collections: Maurice C. Hall, custodian.

Department of Biology—Continued.

Division of Echinoderms: Austin H. Clark, curator.

Division of Plants (National Herbarium): W. R. Maxon, curator; Ellsworth P. Killip, associate curator; Emery C. Leonard, assistant curator; Conrad V. Morton, aid; Egbert H. Walker, aid; John A. Stevenson, custodian of C. G. Lloyd mycological collection.

Section of Grasses: Agnes Chase, custodian.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.

Section of Lower Fungi: D. G. Fairchild, custodian.

Section of Diatoms: Paul S. Conger, custodian.

Associates in Zoology: C. Hart Merriam, Mary J. Rathbun, C. W. Stiles, Theodore S. Palmer, William B. Marshall.

Associate Curator in Zoology: Hugh M. Smith.

Associate in Marine Sediments: T. Wayland Vaughan.

Collaborator in Zoology: Robert Sterling Clark.

Collaborators in Biology: A. K. Fisher, David C. Graham.

Department of Geology:

R. S. Bassler, head curator; Jessie G. Beach, aid.

Division of Physical and Chemical Geology (systematic and applied): W. F. Foshag, curator; Edward P. Henderson, assistant curator.

Division of Mineralogy and Petrology: W. F. Foshag, curator; Frank L. Hess, custodian of rare metals and rare earths.

Division of Stratigraphic Paleontology: Charles E. Resser, curator; Gustav A. Cooper, assistant curator; Margaret W. Moodey, aid for Springer collection.

Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; Paul Bartsch, curator of Cenozoic collection.

Division of Vertebrate Paleontology: Charles W. Gilmore, curator; C. Lewis Gazin, assistant curator; Norman H. Boss, chief preparator.

Associate in Mineralogy: W. T. Schaller.

Associate in Paleontology: E. O. Ulrich.

Associate in Petrology: Whitman Cross.

Department of Arts and Industries:

Carl W. Mitman, head curator.

Division of Engineering: Frank A. Taylor, curator.

Section of Mechanical Technology: Frank A. Taylor, in charge; Fred C. Reed, scientific aid.

Section of Aeronautics: Paul E. Garber, assistant curator.

Section of Mineral Technology: Carl W. Mitman, in charge.

Division of Textiles: Frederick L. Lewton, curator; Mrs. E. W. Rosson, aid.

Section of Wood Technology: William N. Watkins, assistant curator.

Section of Organic Chemistry: Aida M. Doyle, aid.

Division of Medicine: Charles Whitebread, assistant curator.

Division of Graphic Arts: R. P. Tolman, curator; C. Allen Sherwin, scientific aid.

Section of Photography: A. J. Olmsted, assistant curator.

Division of History: T. T. Belote, curator; Charles Carey, assistant curator; Mrs. C. L. Manning, philatelist.

Chief of correspondence and documents.—H. S. Bryant.

Assistant chief of correspondence and documents.—L. E. Commerford.

Superintendent of buildings and labor.—R. H. Trembly.

Assistant superintendent of buildings and labor.—Charles C. Sinclair.

Editor.—PAUL H. OEHSER.
Engineer.—C. R. DENMARK.
Accountant and auditor.—N. W. DORSEY.
Photographer.—A. J. OLMSTED.
Property clerk.—LAWRENCE L. OLIVER.
Assistant librarian.—LEILA F. CLARK.

NATIONAL GALLERY OF ART

Trustees:
The CHIEF JUSTICE of the UNITED STATES.
THE SECRETARY OF STATE.
The SECRETARY of the TREASURY.
The SECRETARY of the SMITHSONIAN INSTITUTION.
DAVID K. E. BRUCE.
DUNCAN PHILLIPS.
S. PARKER GILBERT.
DONALD D. SHEPARD.
ANDREW W. MELLON.

NATIONAL COLLECTION OF FINE ARTS

Acting Director.—RUEL P. TOLMAN.

FREER GALLERY OF ART

Curator.—JOHN ELLERTON LODGE.
Associate curator.—CARL WHITING BISHOP.
Assistant curator.—GRACE DUNHAM GUEST.
Assistant.—ARCHIBALD G. WENLEY.
Superintendent.—JOHN BUNDY.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.
Ethnologists.—JOHN P. HARRINGTON, JOHN N. B. HEWITT, TRUMAN MICHELSON, JOHN R. SWANTON, WILLIAM D. STRONG.
Archeologist.—FRANK H. H. ROBERTS, Jr.
Associate anthropologist.—JULIAN H. STEWARD.
Editor.—STANLEY SEARLES.
Librarian.—MIRIAM B. KETCHUM.
Illustrator.—EDWIN G. CASSEDY.

INTERNATIONAL EXCHANGES

Secretary (in charge).—CHARLES G. ABBOT.
Chief clerk.—COATES W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.
Assistant director.—ERNEST P. WALKER.

ASTROPHYSICAL OBSERVATORY

Director.—Charles G. Abbot.
Assistant director.—Loyal B. Aldrich.
Research assistant.—Frederick E. Fowle, Jr.
Associate research assistant.—William H. Hoover.

DIVISION OF RADIATION AND ORGANISMS

Director.—Charles G. Abbot.
Assistant director.—Earl S. Johnston.
Associate research assistant.—Edward D. McAlister.
Assistant in radiation research.—Leland B. Clark.
Research associate.—Florence E. Meier.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDED JUNE 30, 1937

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1937. The first 24 pages contain a summary account of the affairs of the Institution, and appendixes 1 to 10 give more detailed reports of the operations of the National Museum, the National Collection of Fine Arts, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the Smithsonian library, and of the publications issued under the direction of the Institution. On page 119 is the financial report of the executive committee of the Board of Regents.

OUTSTANDING EVENTS

The most notable event of the year was the establishment of the new National Gallery of Art as a bureau of the Smithsonian Institution, the result of the munificent gift by Andrew W. Mellon of his great art collection and funds exceeding $10,000,000 for the construction of a suitable gallery building.

The equipment of the National Zoological Park was greatly improved by the completion, under a P. W. A. grant, of three new exhibition buildings, a machine shop, a garage, and new heating and electric installations. Dr. W. M. Mann, Director of the Zoo, headed the National Geographic Society-Smithsonian Institution Expedition to Sumatra for the purpose of obtaining specimens of the interesting animals of that region for the National Zoo. The expedition was still in the field at the close of the year, but reports indicate a highly successful trip.

In the Division of Radiation and Organisms, notable advances have been made in the studies of photosynthesis, phototropism, and the reactions of ultraviolet rays on plant growth.

The Smithsonian radio program, a weekly half-hour dramatization of the Institution's researches and exhibits, put on the air through the cooperation of the Office of Education and the National Broadcasting Co., continued throughout the year with undiminished popularity. The little magazine issued in conjunction with the broadcasts, presenting popular articles and reading lists on the subjects treated, had reached a circulation of 150,000 for the June issue.

SUMMARY OF THE YEAR'S ACTIVITIES OF THE BRANCHES OF THE INSTITUTION

National Museum.—The total appropriation for the maintenance of the Museum was $763,970, an actual increase of $28,228 over the previous year. Specimens added to the collections, mainly as gifts or through Smithsonian expeditions, numbered 361,951. It is difficult to select the outstanding accessions among this great amount of valuable material, but the following may be mentioned as examples of the interest of the year's additions: In anthropology, a valuable collection of skeletal material resulting from Dr. Hrdlička's archeological excavations in Alaska; in biology, welcome specimens of the little-known fauna of Siam, including 1,100 birds, 800 fishes, as well as mammals, insects, and other forms; in geology, specimens representing 29 distinct meteoric falls, obtained through the Roebling fund, bringing the number of falls represented in the Museum to 635; in arts and industries, the gondola of the successful stratosphere balloon *Explorer II*, presented by the National Geographic Society. A number of expeditions went out during the year in the interests of the Museum's researches in anthropology, biology, and geology. These were financed mainly by Smithsonian private funds or by the assistance of friends of the Museum. The number of visitors to the several Museum buildings for the first time in its history exceeded 2,000,000, the actual number for the year being 2,288,532. The Museum published an annual report, 2 bulletins, and 29 proceedings separates.

National Collection of Fine Arts.—The name of this bureau of the Institution was changed by act of Congress on March 24, 1937, from "National Gallery of Art" to "National Collection of Fine Arts", in order that the former name might be assigned to the collection of fine arts and the building to house it given by Andrew W. Mellon to the Nation. The sixteenth annual meeting of the National Gallery of Art Commission was held on December 8, 1936. Dr. George Harold Edgell was nominated as a member of the Commission to succeed Joseph H. Gest, deceased. A number of portraits and other art works were accepted by the Commission for the Gallery, and two paintings purchased by the council of the National Academy of Design from the fund provided by the Henry Ward Ranger bequest were recalled and claimed, according to the terms of the Ranger will. Two miniatures were acquired through the Catherine Walden Myer fund. The Gallery held two special exhibitions, as follows: Paintings and etchings by Thomas Moran, installed in the lobby of the Natural History Building on the one hundredth anniversary of the painter's birth; and the exhibition of the Second Annual Metropolitan State Art Contest, 1937, including 305 prints, paintings, and pieces of sculpture, by 148 artists.

Freer Gallery of Art.—The year's additions to the collection include a bronze Cambodian Buddha, a bronze Chinese ceremonial vessel, and three early Chinese mirrors; three Armenian volumes of the fourteenth and seventeenth centuries—the Gospel, a psalter, and a hymnal; a thirteenth century New Testament in Aramaic; Arabic volumes and paper and parchment leaves from several Arabic manuscripts of various periods from the ninth to the seventeenth centuries; a sixteenth century Persian volume and 3 leaves from a Persian manuscript of the same period; 1 Chinese, 4 Indian, and 11 Persian paintings; and in pottery 1 Chinese cup holder and 2 Chinese vases, a Persian bowl, and 2 Syrian pitchers. Curatorial work was devoted to the study of Chinese, Tibetan, Japanese, Aramaic, Armenian, Arabic, Persian, East Indian, and Cambodian objects in the collection and of the texts and seals associated with them. During the year 810 objects and 286 photographs of objects were submitted to the curator for opinion as to provenance, age, quality, or other significance, and 31 inscriptions for translation. Visitors totaled 140,881, and 10 groups were given docent service. Three illustrated talks were given by members of the Gallery staff before three local organizations.

Bureau of American Ethnology.—The researches of the Bureau covered a wide variety of archeological and ethnological studies of the Indians of North, South, and Central America. Mr. Stirling, Chief of the Bureau, completed his ethnological report on the Jivaro Indians of Ecuador, and examined a number of mounds in Georgia and Florida. Dr. Swanton, as chairman of the United States De Soto Expedition Commission, made two field trips through that part of the South crossed by De Soto's route; he later completed a 600-page report, which was submitted by the Commission to Congress. Dr. Michelson continued his ethnological researches among the Algonquian tribes of James and Hudson Bays, Canada. Dr. Harrington prepared papers on ethnological and linguistic subjects relating to a number of tribes including the Karuk, Kiowa, Navaho, Apache, Hopi, and Shoshonean; he also completed a report on the Siberian origin of the American Indian. Dr. Roberts continued his archeological excavations at the Lindenmeier site in Colorado, adding important material to that which he had already discovered relating to Folsom man. In March 1937 he represented the United States at the International Conference of Archeologists at Cairo, Egypt. Dr. Strong devoted the year to completing the report on his archeological expedition of the previous year to Honduras. Dr. Steward continued ethnological studies of the Shoshonean tribes of the Great Basin and Plateau areas. Mr. Hewitt continued his researches on the League of the Iroquois. The Bureau published its annual report and one bulletin.

International exchanges.—Since the conclusion at Brussels in 1886 of two exchange conventions between the United States and a number of other countries, the Smithsonian Institution has been charged by Congress with the important duty of carrying on the exchange with other countries of governmental and scientific documents on behalf of the United States. During the year the exchange service handled a total of 657,346 packages weighing 651,461 pounds. The number of full and partial sets of governmental publications forwarded abroad is now 111, and 105 copies of the Congressional Record and the Federal Register are sent to other countries in exchange for their parliamentary journals. Four new depositories in Switzerland were added to the interparliamentary exchange list, and one in Germany, the Bibliothek des Preussischen Landtags, Berlin, was discontinued, as the Lantags was abolished.

National Zoological Park.—The fiscal year 1937 was outstanding in the history of the Zoo. The construction under the P. W. A. grant of $892,920 of five new buildings was completed. Under this same grant, three 250-horsepower down-draft boilers were installed in the central heating plant, the conduit system was extended to two mammal houses, and the electric supply distribution system was rearranged. An expedition headed by Dr. William M. Mann, Director of the Zoo, and financed by the National Geographic Society left Washington in January to collect animals in the Far East for the Zoo. They took with them 28 animals which were intended for zoos in the regions visited. The expedition is expected to return to Washington in October with a large collection of rare animals, advance reports indicating that the trip has been a very successful one. Accessions of animals during the year numbered 1,067. Losses by death and otherwise totaled 916, leaving the collection at the close of the year at 2,342 animals, representing 701 different species. Visitors numbered 2,435,520, including groups from 638 schools and organizations from 20 States and the District of Columbia.

Astrophysical Observatory.—Measurements of the solar constant of radiation have been continued on all favorable days (amounting to about 80 percent of all days) at the three Smithsonian observing stations at Table Mountain, Calif.; Montezuma, Chile; and Mount St. Katherine, Egypt. A flaw was discovered in the "short method" reduction of observations, used since 1923, making it necessary to devise a new method. After this was done, the field observers remeasured the photographic records of observation since that date, and great progress has been made by an augmented computing staff at Washington in recomputing by the new method all observations since 1923. A solar radiation steam boiler (pl. 7) was prepared under the direction of Dr. Abbot and successfully operated in September 1936. Dr. Abbot later devised a small solar flash boiler which embodies many improvements and which holds much promise of practical application in the future. Frederick E. Fowle, a member of the staff of the Astrophysical Observatory since 1894, was retired for disability at the close of the fiscal year.

Division of Radiation and Organisms.—The staff of the Division obtained important results from studies on the following subjects: the normal growth of tomatoes under laboratory conditions; photosynthesis in wheat; perfection of a spectral absorption method of measuring carbon dioxide concentration in air; time relations in photosynthesis; the efficiency of different wave lengths of light to promote germination in light-sensitive lettuce seed; the inactivation of plant growth substance by light; and the stimulation of multiplication in algae by minute dosage of ultraviolet rays known to be lethal in doses of sufficient intensity. Four papers describing the investigations of the staff were published during the year in the Smithsonian Miscellaneous Collections, and others were in preparation.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The law establishing the Institution specifies that the three Senator Regents shall serve during the term for which they shall hold, without reelection, their office as Senators, and the three Members of the Senate on the Board of Regents, Joseph T. Robinson, of Arkansas; M. M. Logan, of Kentucky; and Charles L. McNary, of Oregon, having been reelected to the Senate for a new term beginning January 3, 1937, the Vice President on January 6, 1937, reappointed them to succeed themselves on the Board of Regents.

The roll of Regents at the close of the year was as follows: Charles Evans Hughes, Chief Justice of the United States, Chancellor; John N. Garner, Vice President of the United States; members from the Senate—Joseph T. Robinson, M. M. Logan, Charles L. McNary; members from the House of Representatives—T. Alan Goldsborough, Clarence Cannon, Charles L. Gifford; citizen members—Frederic A. Delano, Washington, D. C.; John C. Merriam, Washington, D. C.; R. Walton Moore, Virginia; Robert W. Bingham, Kentucky; Augustus P. Loring, Massachusetts; Roland S. Morris, Pennsylvania.

Proceedings.—The annual meeting of the Board of Regents was held on January 14, 1937. The Regents present were Chief Justice Charles Evans Hughes, Chancellor; John N. Garner, Vice President of the United States; Senators Joseph T. Robinson and M. M. Logan; Representatives T. Alan Goldsborough, Charles L. Gifford, and Clarence Cannon; citizen Regents Frederic A. Delano and R. Walton Moore; and the Secretary, Dr. Charles G. Abbot.

The Secretary presented his annual report, detailing the activities of the several Government branches and of the parent institution during the year, and Mr. Delano presented the report of the executive committee, covering financial statistics of the Institution. The Secretary also presented the annual report of the National Gallery of Art Commission.

In lieu of his usual special report the Secretary presented to the Regents a brief review of the principal achievements of the Smithsonian Institution during the 10 years since the death of Secretary Walcott in 1927. In accordance with the wishes of the Regents, this résumé has been printed in pamphlet form.

The Regents also adopted resolutions approving in principle the proposed gift of the Hon. Andrew W. Mellon of a collection of masterpieces of painting and sculpture, and of a gallery to house them. This matter is treated in detail on pages 7–17 of this report.

In addition to the annual meeting, there was a special meeting of the Board of Regents on June 24, 1937, at which the following Regents were present: Senators Joseph T. Robinson and M. M. Logan; Representatives T. Alan Goldsborough and Clarence Cannon; citizen Regent Roland S. Morris; and the Secretary, Dr. Charles G. Abbot. This meeting was called to take action on matters connected with the above-mentioned offer by the Hon. Andrew W. Mellon, of which full details will be found on pages 7–17.

FINANCES

A statement will be found in the report of the executive committee, page 119.

MATTERS OF GENERAL INTEREST

ANDREW W. MELLON'S ART GIFT TO THE NATION

Probably the greatest impetus ever given to the development of art in the Nation's Capital and in the Nation itself will result from Andrew W. Mellon's munificent gift to the American people of his unexcelled art collection, a $10,000,000 building to exhibit it, and an endowment fund to pay the salaries of the directing officials and for the acquisition of additional art works. The proposal was made by Mr. Mellon in a letter to President Roosevelt dated December 22, 1936, which began as follows:

> Over a period of many years I have been acquiring important and rare paintings and sculpture with the idea that ultimately they would become the property of the people of the United States and be made available to them in a national art gallery to be maintained in the city of Washington for the purpose of encouraging and developing a study of the fine arts.
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> In order to carry out this purpose, and with the approval of the other trustees, I wish to propose a plan to give the art collection which I have brought together to the Smithsonian Institution or to the United States Government for the benefit of the people of this country, and also to erect or cause to be erected on public land a suitable building for a national gallery of art, the design and materials of which shall be subject to the approval of the Fine Arts Commission.

Following an exchange of correspondence with the President, Mr. Mellon made his formal offer in a letter dated December 31, 1936. In consultation with representatives of the Department of Justice and the Secretary of the Smithsonian Institution a bill was prepared by representatives of Mr. Mellon as House Joint Resolution 217 covering the matter. After hearings, the resolution was agreed to by Congress and approved by the President on March 24, 1937. The full text of the resolution follows:

> *Resolved by the Senate and House of Representatives of the United States of America in Congress assembled*, That the area bounded by Seventh Street, Constitution Avenue, Fourth Street, and North Mall Drive, Northwest, in the District of Columbia, is hereby appropriated to the Smithsonian Institution as a site for a National Gallery of Art. The Smithsonian Institution is authorized to permit the A. W. Mellon Educational and Charitable Trust (hereinafter referred to as the donor) to construct on said site for the Smithsonian Institution a building to be designated the National Gallery of Art, and to remove any existing structure and landscape the grounds within said area. The adjoining area bounded by Fourth Street, Pennsylvania Avenue, Third Street, and North Mall Drive, Northwest, in the District of Columbia, is hereby reserved as a site for

future additions to the National Gallery of Art. The project shall be in accordance with plans and specifications approved by the Commission of Fine Arts.

Sec. 2. (a) There is hereby established in the Smithsonian Institution a bureau, which shall be directed by a board to be known as the Trustees of the National Gallery of Art, whose duty it shall be to maintain and administer the National Gallery of Art and site thereof and to execute such other functions as are vested in the board by this Act. The board shall be composed as follows: The Chief Justice of the United States, the Secretary of State, the Secretary of the Treasury, and the Secretary of the Smithsonian Institution, ex officio; and five general trustees who shall be citizens of the United States, to be chosen as hereinafter provided. No officer or employee of the Federal Government shall be eligible to be chosen as a general trustee.

(b) The general trustees first taking office shall be chosen by the Board of Regents of the Smithsonian Institution, subject to the approval of the donor, and shall have terms expiring one each on July 1 of 1939, 1941, 1943, 1945, and 1947, as designated by the Board of Regents. A successor shall be chosen by a majority vote of the general trustees and shall have a term expiring ten years from the date of the expiration of the term for which his predecessor was chosen, except that a successor chosen to fill a vacancy occurring prior to the expiration of such term shall be chosen only for the remainder of such term.

Sec. 3. Upon completion of the National Gallery of Art, the board shall accept for the Smithsonian Institution as a gift from the donor a collection of works of art which shall be housed and exhibited in the National Gallery of Art.

Sec. 4. (a) The faith of the United States is pledged that, on completion of the National Gallery of Art by the donor in accordance with the terms of this Act and the acquisition from the donor of the collection of works of art, the United States will provide such funds as may be necessary for the upkeep of the National Gallery of Art and the administrative expenses and costs of operation thereof, including the protection and care of works of art acquired by the board, so that the National Gallery of Art shall be at all times properly maintained and the works of art contained therein shall be exhibited regularly to the general public free of charge. For these purposes there are hereby authorized to be appropriated such sums as may be necessary.

(b) The board is authorized to accept for the Smithsonian Institution and to hold and administer gifts, bequests, or devises of money, securities, or other property of whatsoever character for the benefit of the National Gallery of Art. Unless otherwise restricted by the terms of the gift, bequest, or devise, the board is authorized to sell or exchange and to invest or reinvest in such investments as it may determine from time to time the moneys, securities, or other property composing trust funds given, bequeathed, or devised to or for the benefit of the National Gallery of Art. The income as and when collected shall be placed in such depositaries as the board shall determine and shall be subject to expenditure by the board.

(c) The board shall appoint and fix the compensation and duties of a director, an assistant director, a secretary, and a chief curator of the National Gallery of Art, and of such other officers and employees of the National Gallery of Art as may be necessary for the efficient administration of the functions of the board. Such director, assistant director, secretary, and chief curator shall be compensated from trust funds available to the board for the purpose, and their appointment and salaries shall not be subject to the civil-service laws or the Classification Act of 1923, as amended. The director, assistant director, secretary, and chief curator shall be well qualified by experience and training to perform the duties of their office and the original appointment to each such office shall be subject to the approval of the donor.

(d) The actions of the board, including any payment made or directed to be made by it from any trust funds, shall not be subject to review by any officer or agency other than a court of law.

SEC. 5. (a) The board is authorized to adopt an official seal which shall be judicially noticed and to make such bylaws, rules, and regulations, as it deems necessary for the administration of its functions under this Act, including, among other matters, bylaws, rules, and regulations relating to the acquisition, exhibition, and loan of works of art, the administration of its trust funds, and the organization and procedure of the board. The board may function notwithstanding vacancies, and three members of the board shall constitute a quorum for the transaction of business.

(b) In order that the collection of the National Gallery of Art shall always be maintained at a high standard and in order to prevent the introduction therein of inferior works of art, no work of art shall be included in the permanent collection of the National Gallery of Art unless it be of similar high standard of quality to those in the collection acquired from the donor.

(c) The board shall have all the usual powers and obligations of a trustee in respect of all trust funds administered by it and all works of art acquired by it.

(d) The board shall submit to the Smithsonian Institution an annual report of its operations under this Act, including a detailed statement of all acquisitions and loans of works of art and of all public and private moneys received and disbursed.

SEC. 6. (a) The Commissioners of the District of Columbia are hereby authorized and directed to close Sixth Street, Northwest, within the boundaries of the site for the National Gallery of Art. The National Capital Park and Planning Commission shall determine the building lines and approve the plan of approaches for said gallery, and shall also make recommendations for the widening and adjustment of Third, Seventh, Ninth, and such other streets in the vicinity as may be necessary and desirable to provide for the traffic which would otherwise use Sixth Street.

(b) Section 10 of the Public Building Act, approved March 4, 1913 (37 Stat. L., p. 881), relating to the George Washington Memorial Building, and all provisions of law amendatory thereof, are hereby repealed.

(c) The existing bureau of the Smithsonian Institution now designated as a national gallery of art shall hereafter be known as the National Collection of Fine Arts.

(d) The fifth paragraph under the heading "Smithsonian Institution" in the Independent Offices Appropriation Act for the fiscal year 1924, approved February 13, 1923 (42 Stat. L. 1235), relating to the erection of a national gallery of art, is hereby repealed.

Approved, March 24, 1937.

At a special meeting of the Board of Regents of the Institution held on June 24, 1937, there were submitted copies of a trust indenture between the A. W. Mellon Educational and Charitable Trust, the Smithsonian Institution, and the trustees of the National Gallery of Art. After consideration, the following resolution was adopted:

Resolved: That the trust indenture between the A. W. Mellon Educational and Charitable Trust, the Smithsonian Institution and the trustees of the National Gallery of Art, a draft whereof has been presented at this meeting, and hereby is directed to be inserted in the minute book of the Regents immediately following the minutes of this meeting, be, and hereby it is, approved, and the Secretary of the Institution be, and hereby he is, authorized and directed to execute such indenture, in triplicate, in the name and under the corporate seal of this Institution, and upon its due execution and by the other parties thereto to make proper delivery thereof.

The full text of the trust indenture is as follows:

TRUST INDENTURE

Dated the 24th day of June 1937, and intended to be effective upon that date, although executed by the parties hereto on various other dates, by, between, and among

Andrew W. Mellon, Paul Mellon, Donald D. Shepard and David K. E. Bruce, as trustees of the A. W. Mellon Educational and Charitable Trust, established under and by virtue of a deed of trust of Andrew W. Mellon to said trustees, dated December 30, 1930, parties of the first part, and hereinafter sometimes referred to as the "Donor";

Smithsonian Institution, an establishment created and existing under and by virtue of an act of the Congress of the United States of America, approved August 10, 1846, party of the second part, and hereinafter referred to as the "Institution"; and

The trustees of the National Gallery of Art, constituted under and by virtue of a Joint Resolution of the Congress of the United States, entitled "Joint Resolution providing for the Construction and Maintenance of a National Gallery of Art," approved March 24, 1937, parties of the third part, and hereinafter sometimes referred to as the "Trustees."

Whereas in December 1936, by correspondence between the President of the United States of America and Andrew W. Mellon, the donor proposed to give a collection of works of art for the benefit of the people of the United States of America and to cause to be erected on public land a suitable building in which to house and exhibit such collection, copies of such correspondence being hereunto attached and made part hereof; and

Whereas by said joint resolution of the Congress, there was established a bureau in the Institution to be directed by the trustees, and provision was made for the construction of said building, the acceptance of a collection of works of art as a gift from the donor and the exhibition thereof and of other appropriate works of art in said building, and the administration by the trustees of said building, the site and contents thereof, and all matters and affairs that pertain to the use thereof for the public benefit; and

Whereas it is now desired to consummate the gift of said building and said collection of works of art and to specify more particularly the terms and conditions upon which said gift is made by the donor and accepted by the Institution and the trustees, and

Whereas by said correspondence, one of the conditions of the gift was that the upkeep of the gallery building and other administrative expenses and costs of operation and functioning of the gallery would be provided for annually in appropriations to be made by Congress; and by said joint resolution, the faith of the United States was pledged that it would provide such funds as would be necessary for the upkeep of the gallery and the administrative expenses and costs of operation thereof, including the protection and care of works of art acquired by the trustees;

Now, THEREFORE, THIS INDENTURE WITNESSETH:

I

ERECTION OF THE NATIONAL GALLERY OF ART

In accordance with the provisions of said joint resolution of the Congress, the Institution hereby permits the donor to construct, and the donor hereby agrees to construct for the Institution, a building to be designated and hereinafter referred to as the "National Gallery of Art" upon the area bounded by Seventh Street, Constitution Avenue, Fourth Street, and North Mall Drive, N. W., in the District of Columbia (being the site appropriated to the Institution by said joint resolution), and to remove any existing structure and to landscape the grounds within said area, all in accordance with plans and specifications approved by the Commission of Fine Arts. The building line and plans of approaches for said building shall be approved by the National Capital Park and Planning Commission. The donor, in its uncontrolled discretion but at its sole expense, shall engage such architects, contractors, builders, and others, and shall take or cause to be taken any and every other action necessary or advisable in connection with the construction, completion, equipment, and furnishing of said building, and the landscaping of said area upon which it is erected. The donor shall pay all costs and expenses in connection with, or incident to, said project. In no event and under no circumstances shall the Institution or the trustees be responsible or liable for any part of such cost or expense, and the donor shall indemnify and save harmless the Institution and the trustees from any and every liability whatsoever with reference to anything done or omitted to be done in connection with the carrying out of said project or any part thereof. The Institution and the trustees are expressly relieved of any responsibility or duty pertaining to said project, and the entire and exclusive jurisdiction and responsibility thereover and with regard thereto are imposed upon and vested in the donor. Said project shall be commenced as soon after the execution and delivery hereof as, in the judgment of the donor, the necessary plans, specifications, and arrangements can be made and effected, and will be proceeded with as expeditiously as, in the judgment of the donor, the execution of the work can properly be effected, but as the building is of monumental character and is intended to have outstanding architectural merit, it is agreed that undue haste is not desirable, and no time for the final completion of the project can be fixed. As and when said project shall be finally completed by the construction, equipment, and furnishing of said building and the landscaping of said area in accordance with said plans and specifications, the donor will give written notice thereof to the Institution and the trustees and thereupon, without further action by any of the parties hereto, the legal title to said building shall be deemed to be vested in the Institution, but the maintenance and administration of said building and of the site shall be vested exclusively in, and shall be the sole obligation and duty of, the trustees as a separate bureau of the Institution, and distinct from the other activities of the Institution, which are under the management of its Board of Regents.

II

NAME OF GALLERY

Said gallery shall be known and designated perpetually as the "National Gallery of Art", to which the entire public shall forever have access, subject only to reasonable regulations from time to time established by the trustees.

III

GIFT OF COLLECTIONS OF WORKS OF ART

The donor hereby gives to the Institution and the trustees, and they hereby accept from the donor, in trust, however, for the uses and purposes and subject to the provisions and conditions hereinafter expressed, the collection of works of art listed in the schedule hereto attached, made part hereof and marked "Exhibit 1."

IV

CUSTODY OF COLLECTION PENDING COMPLETION OF THE NATIONAL GALLERY OF ART

Pending the completion of the National Gallery of Art, said collection of works of art shall remain in the custody of the donor. During such period of custody, the donor will care for all said works of art, and will keep the same insured in favor of the Institution and the trustees, as their respective interests may appear, against loss or damage by fire, theft, or burglary, in such amounts and with such parties as the donor, in its discretion, may determine, if and to the extent that such insurance may be obtainable. The donor shall pay all costs, premiums, and other charges incident to such care and insurance. Upon the completion of the National Gallery of Art, said collection shall be delivered to the trustees and thereafter shall remain under their exclusive control.

V

PASSAGE OF TITLE AND RESPECTIVE FUNCTIONS OF INSTITUTION AND OF TRUSTEES

Forthwith upon the execution and delivery hereof, the title to said collection of works of art shall pass to and be vested in the Institution. While it is the intention that the title to said works of art shall be forever vested in the Institution, yet it is also the intention of the parties hereto, and this gift is made upon the express understanding, agreement, and trust, that from and after the completion of the National Gallery of Art, the actual custody, control, management, and exhibition of said works of art, as well as of such other works of art as, in accordance with the provisions of said joint resolution, from time to time may be housed or exhibited in said National Gallery of Art, and all the details pertaining thereto, shall be, and hereby are, delegated to and vested solely, exclusively and forever in the trustees.

VI

DISPLAY OF COLLECTION

Subject to the subsequent provisions of this section VI, the said collection of works of art shall always be kept in the National Gallery of Art, and none thereof shall be removed from said building or from their settings therein except for most cogent reasons therefor, such as repairs to said building or said works of art, or temporary exhibition of some of such works of art elsewhere, and then only with the prior approval of a majority of the entire membership of the trustees. The works of art constituting said collection shall receive such care and attention from time to time as shall be necessary for their preservation and exhibition, shall always be exhibited in said National Gallery of Art in spacious arrangement so that overcrowding will be avoided, and shall always be displayed with dignity, in appropriate units, with suitable settings and with due regard to their importance and quality.

While the parties hereto presently recognize that all the works of art constituting said collection are of such high standard of quality that it is essential that such collection perpetually remain intact and be a part of the permanent collection on exhibition in the National Gallery of Art, and such is the purport of this indenture, the donor at the same time recognizes the inadvisability of perpetually foreclosing any discretion in the trustees in regard to the disposition of any of the works of art constituting such collection and, consequently, the donor authorizes and empowers the trustees, but only upon the prior approval of not less than three-fourths of the entire membership of the trustees, to exchange or otherwise dispose of any particular work of art then a part of said collection, if in such exchange or by reason of such other disposition the trustees are enabled to obtain for the Institution, to be and become a part of the collection under this Indenture, some other work of art which, in the judgment of the trustees, would be a highly desirable acquisition to such collection. Furthermore, the donor recognizes that with the passing of time it may come to be thought by at least three-fourths of the entire membership of the trustees that some particular work of art, then constituting a part of said collection, has become unsuitable longer to remain as a part of said collection, and therefore the donor provides that in the event that, in the opinion of at least three-fourths of the entire membership of the trustees, any particular work of art then a part of said collection is not in keeping with said collection as a whole, the trustees are authorized and empowered to make such disposition thereof as they, in their uncontrolled discretion, shall deem advisable by sale, exchange, gift, loan, or otherwise.

VII

MAINTENANCE OF THE NATIONAL GALLERY OF ART

The National Gallery of Art shall be the permanent home of the said collection of works of art hereby given by the donor. It shall be used exclusively for the storage and exhibition of works of art and the administration of the affairs of the trustees. In order that the collection of the National Gallery of Art shall always be maintained at a high standard and to prevent the introduction therein of inferior works of art, no work of art shall be included in the permanent collection of the National Gallery of Art unless it be of similar high standard of quality to those in the collection hereby given by the donor. The building and the contents and operations thereof shall at all times remain in the exclusive jurisdiction and control of the trustees in accordance with such by-laws, rules, and regulations as they from time to time shall prescribe.

It is an express condition of the trust of said collection of works of art, hereby created, that the faith of the United States is pledged that, on completion of the National Gallery of Art by the donor in accordance with the terms of said joint resolution and the acquisition from the donor of the collection of works of art, the United States will provide such funds as may be necessary for the upkeep of the National Gallery of Art and the administrative expenses and costs of operation thereof, including the protection and care of works of art acquired by the Board, so that the National Gallery of Art shall be at all times properly maintained and the works of art contained therein shall be exhibited regularly to the general public free of charge.

VIII

THE TRUSTEES

The trustees shall always be not less than nine persons, of whom a minority, to be known as ex-officio trustees, shall be officers of the United States or of the Institution, ex-officio, and of whom a majority to be known as general trustees, shall be citizens of the United States, none of whom at the time of his or her election to the office of general trustee shall be an officer or employee of the United States of America. Any vacancy in the office of general trustee by reason of the expiration of the term, death, or resignation of the incumbent, or otherwise howsoever, shall be filled by the election of a competent person by a majority of the remaining general trustees.

IX

ALTERATION OR MODIFICATION OF THIS INDENTURE

(*a*) During the existence of the donor

At any time and from time to time hereafter, with the consent of the Institution, the trustees, and the donor, this trust indenture may be altered, modified, or supplemented in any respect whatever, as the parties hereto may deem advisable or necessary, which shall not be inconsistent with the general purpose and scope of this trust indenture and of the said joint resolution.

(*b*) After the termination of the donor

While this trust indenture is entered into by the parties hereto with the intention, and it is the purport hereof, that the trust hereby created shall be administered strictly in accordance with the terms, provisions, and conditions of this indenture and of said joint resolution, the parties hereto recognize that with the passing of time and changed conditions, some of such terms, provisions, or conditions may become inconvenient or impossible of observance or the observance thereof may become detrimental to the primary purpose of the donor that the National Gallery of Art and the contents thereof, including the donor's collection of works of art, shall at all times be available for the benefit and enjoyment of the public, or situations or conditions, not now thought of or inadequately provided for in this indenture, may arise and the proper administration of this trust may require such conditions or situations to be properly and practically dealt with, and consequently, the parties hereto agree and expressly provide that if at any time and from time to time, but only after the termination of the A. W. Mellon Educational and Charitable Trust by the terms of the deed of trust creating such trust or otherwise, three-fourths of the entire membership of the trustees and three-fourths of the entire number of the regents or other duly constituted governing body of the Institution shall be of the opinion that in order properly to administer the National Gallery of Art and the site and contents thereof in the interest and for the benefit of the public, this indenture of trust should be altered, modified, or amended as respects any of its terms, provisions, or conditions, or should be supplemented so as adequately to provide for new conditions or situations, then and in every such event the trustees, with the approval of at least three-fourths of the entire membership of the trustees, and the Institution, pursuant to approval of at least three-fourths of its Board of Regents or other duly constituted authority, shall have the right, power, and authority, by supplemental indenture, to effect any such alteration, modification, or amendment hereof, or supplement hereto, provided however, that no alteration, modification, or amendment of this trust indenture, or any supplement thereof, shall be made which shall be in violation of the provisions of said joint resolution or of any future act of Congress relating to the National Gallery of Art; and provided further, that in no event and under no circumstance shall this trust indenture be altered, modified, amended, or supplemented as respects the provisions of article VIII hereof, it being the intention and one of the express conditions of the gift hereby made by the donor that the trust hereby created shall perpetually be administered by trustees constituted in accordance with the provisions of article VIII hereof.

For the purpose of this section IX, the A. W. Mellon Educational and Charitable Trust shall be conclusively deemed to have been terminated if three-fourths of the entire membership of the trustees, after such careful inquiry as they shall deem to be sufficient, shall be of the opinion that such trust no longer continues to exist.

In witness whereof, the A. W. Mellon Educational and Charitable Trust has caused this indenture of trust to be executed by the hands and seals of the trustees thereof; the Smithsonian Institution, pursuant to a resolution duly adopted by its Board of Regents, has caused this indenture of trust to be signed and its official seal to be hereunto affixed by its secretary; and the trustees of the National Gallery of Art have caused this indenture of trust to be executed by the hands and seals of the trustees, all as of the day and year first above written.

THE A. W. MELLON EDUCATIONAL
AND CHARITABLE TRUST,
By (Signed) ANDREW W. MELLON,
(Signed) PAUL MELLON,
(Signed) DONALD D. SHEPARD,
(Signed) DAVID K. E. BRUCE,
Trustees thereof.

SMITHSONIAN INSTITUTION,
[SEAL] By (Signed) C. G. ABBOT, *Secretary.*

NATIONAL GALLERY OF ART,
By (Signed) CHARLES EVANS HUGHES,
(Signed) CORDELL HULL,
(Signed) HENRY MORGENTHAU, Jr.,
(Signed) C. G. ABBOT,
(Signed) A. W. MELLON,
(Signed) DAVID K. E. BRUCE,
(Signed) DUNCAN PHILLIPS,
(Signed) S. PARKER GILBERT,
(Signed) DONALD D. SHEPARD,
Trustees thereof.

At the same meeting of the Board of Regents the following gentlemen were appointed as general trustees of the National Gallery of Art:

Mr. Donald D. Shepard, for the term expiring July 1, 1939;
Mr. S. Parker Gilbert, for the term expiring July 1, 1941;
Mr. Duncan Phillips, for the term expiring July 1, 1943;
Mr. David K. E. Bruce, for the term expiring July 1, 1945;
Mr. A. W. Mellon, for the term expiring July 1, 1947.

Following this final step in the consummation of Mr. Mellon's gift to the Nation, work was started promptly on the preparation of the site. The architect selected for the building by Mr. Mellon was John Russell Pope, the architect for many art galleries, museums, and public buildings here and abroad, including the National Archives Building, Constitution Hall, the Masonic Temple, and others in Washington. According to Mr. Pope, the building will follow the finest traditions of American architecture and will be carefully scaled in proportion with the surrounding buildings. Constructed of marble, the gallery will be 829 feet long, about 350 feet wide at its greatest width, with the central dome 150 feet high. Mr. Pope has assured that the building will incorporate all the best features of the world's art galleries, and in certain respects will be in advance of any existing gallery, notably in relation to lighting and in provision to lessen the fatigue of visitors.

Regarding the collection itself, which will be installed in the building upon its completion and which will form the nucleus and establish the standard of excellence of the National Gallery of Art, the following brief description was given before the House Committee on the Library by Mr. David E. Finley:

> Mr. Mellon has been making this collection for more than 40 years. It is not large as regards the number of pictures. It contains something like a hundred paintings by old masters. But practically all are important, for Mr. Mellon has tried to buy not only paintings by the greatest masters, but also the best examples of their work obtainable. As a result, everyone who sees the collection—and many of the greatest experts in this country and Europe have seen it—is impressed with the exceptional quality of the pictures.
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> In range it covers all the important schools of western European painting. The Italian school is particularly well represented by painters such as Raphael, Perugino, Botticelli, Fra Angelico, Titian, Bellini, Antonella di Messina, and by such rare and early masters as Cimabue, Masaccio, and Andrea del Castagno. There is a Byzantine Madonna and Child, painted in Constantinople early in the thirteenth century, which takes the collection back to the very source of western art, and with the other paintings gives a historical sequence to the collection that will prove very valuable to students.
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> The Flemish school is represented by most of its greatest painters, beginning with the Annunciation by Jan van Eyck, and continuing through Petrus Christus, Rogier van der Weyden, Memling, Gerard David, and ending with two magnificent Rubens from the Hermitage Gallery and three Van Dycks, including the exceptionally fine portrait, painted in Genoa, of the Marchesa Balbi.
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> In the Dutch school there are several outstanding examples of Rembrandt and Frans Hals and three Vermeers, as well as several Hobbemas, and works by Terburg, Metsu, deHoogh, and so forth.
>
> The Spanish paintings include three portraits by Velasquez, one of Pope Innocent X from the Hermitage, being particularly important. There are also four Goyas and two El Grecos, while the German and French paintings include such names as Holbein, Dürer, and Chardin. The British school is quite

largely represented by works of Gainsborough, Reynolds, Raeburn, Romney, Lawrence, Hopner, Turner, and Constable.

In addition to these paintings, Mr. Mellon also acquired a number of portraits by important American painters, such as Gilbert Stuart, Copley, West, Sully, and others. He bought also, in its entirety, the Clarke collection of American portraits, containing some 175 paintings by practically all our earlier well-known American painters. This was not done with the idea that these should go into the National Gallery of Art, but rather that such as were suitable and of general or historic interest should form the nucleus of a National Portrait Gallery, which should be entirely distinct from the art gallery and would be housed, eventually at least, in its own building. A few of the finest of these portraits, which have the greatest artistic merit, will find their place in the art gallery and will form a fitting sequence to the British art of the eighteenth century represented in the collection.

There is just one other matter that I must mention. Mr. Mellon's idea had been originally that the gallery should be for paintings only. Then an opportunity came to buy the Dreyfus collection of Renaissance sculpture—a collection that had been in the making in Paris for many years and included outstanding works by such great artists as Donatello, Verrocchio, Desiderio da Settignano, Luca della Robbia, and others. Naturally, such an opportunity could not be refused and he acquired these sculptures. He also bought two very important large bronzes by Sansovino and a Mercury by Giovanni da Bologna, all of which will find their place in the new gallery, either with the paintings or near them.

This report covers only the year ending June 30, 1937, but to anticipate slightly the next fiscal year, I must record here with profound regret the death of Mr. Mellon on August 26, 1937, and of Mr. Pope on August 27, 1937. It is indeed tragic that these two men could not have lived to see the completion of this splendid project—a remark which will be repeated by many of the millions of Americans who in future years will enter the National Gallery of Art to benefit from Mr. Mellon's patriotic gift to the Nation.

PROPOSED SMITHSONIAN GALLERY OF ART

On March 15, 1937, a joint resolution was introduced in the House of Representatives by Mr. Keller of Illinois to establish a Smithsonian Gallery of Art for the proper housing and display of the national collections of fine arts. These collections have been in the custody of the Smithsonian Institution for many years, and since 1920 have been administered by the Institution as a Government bureau officially designated the National Gallery of Art. Lacking a building for their public exhibition, these valuable art collections have been shown in the Natural History Building of the United States National Museum. With the creation in 1937 of the new National Gallery of Art as a result of the munificent gift of Andrew W. Mellon, the Smithsonian gallery was officially renamed the National Collection of Fine Arts. It is for the proper housing of this collection, now valued at approximately $10,000,000, that the present joint resolution provides.

The resolution sets aside a tract of land on the Mall between Twelfth and Fourteenth Streets and Constitution Avenue and North Mall Drive; creates a Smithsonian Gallery of Art Commission to make preliminary investigations and obtain designs for the building; authorizes the appropriation of $4,800,000 for the building; authorizes annual appropriations for the maintenance of the gallery; and states the policy of the gallery as follows:

> SEC. 7. It shall be the policy of the gallery to maintain a worthy standard for the acceptance of art objects for exhibition in the Smithsonian Gallery of Art; to foster by public exhibitions from time to time in Washington and other parts of the United States a growing public appreciation of art both of past and contemporary time; and further, as funds are available, to encourage the development of art by the purchase of worthy examples of contemporary or other art works, and to invite the private donation of funds therefor.
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> SEC. 8. The Smithsonian Gallery of Art shall be under the administration of the Regents and Secretary of the Smithsonian Institution.

The resolution did not pass the first session of the Seventy-fifth Congress, but it is hoped that favorable action may be taken at the next session.

For many years the Smithsonian Institution has urged the construction of a suitable building for the housing and public exhibition of the art collections belonging to the Nation. These collections contain many works of art of high quality, mainly gifts from private citizens, and there is no doubt that many more such gifts would be made were proper exhibition space available. As much of the collection as possible has been exhibited to the public in the halls of the National Museum, but the available space there was not specifically designed for the display of art works, and in spite of being overcrowded, the space is entirely inadequate, so that many things which should be on exhibition are forced into storage. It is the urgent hope of the Institution that the proposed Smithsonian Gallery of Art may become a reality in the near future.

It will in no sense be a duplication of the newly received National Gallery, for the National Gallery is restricted to classic painting and sculpture, leaving the fields of National collections in contemporary art of all kinds, portraits, jewels, glass, tapestry, and other kinds of art unprovided for. There is already a large national collection of such objects, and every reason to expect great increase if a suitable gallery were available.

SMITHSONIAN RADIO PROGRAM

The Smithsonian's newest activity, its weekly radio broadcast in cooperation with the United States Office of Education and the

National Broadcasting Co., has now operated for a full year. The series, known as "The World is Yours", was initiated by the Office of Education as part of the radio project of the Works Progress Administration. Its purpose was to bring to the people of the United States more of the wealth of knowledge and vitally interesting information on the earth and its inhabitants available in the laboratories and exhibit halls of the Smithsonian Institution. It was further intended as a pioneering experiment in educational radio to determine the most effective means of presenting to a Nation-wide audience solid information in a form that would hold the listener's interest. Before listing the titles of the broadcasts and telling something of the success of the series, it may be of interest to describe briefly the series itself.

The character of the series and the subjects to be covered were worked out in collaboration between the radio experts of the Office of Education and the Smithsonian's editorial office. The basic requirement was that each subject must be presented in dramatized form. Radio lectures and dialogues have apparently failed to hold the listener's interest, but dramatic incidents well written and produced appeal to listeners of all age groups. The subjects to be dramatized covered all phases of the Institution's activities—science in all its branches, art, invention, and history. About half of the year's broadcasts were on Smithsonian research activities, the other half being based on the exhibits in the National Museum and the art galleries under the Institution's direction. The various subjects were carefully planned to come around in fairly regular rotation, so that those listeners with decided preferences for one or another feature could count on hearing their favorite subjects if they listened regularly.

The subject once selected for a particular broadcast, the Office of Education's expert script writers conferred with the Smithsonian authority in that field. After preliminary research, they then prepared the script, which was carefully checked by the Smithsonian. The script then went to New York, where it was produced by the National Broadcasting Co. in their Radio City studios by a selected cast.

Beginning on June 7, 1936, the series covered up to June 30, 1937, the following subjects:

	1936
The Smithsonian, and Famous Exhibits	June 7
Scientific Explorations	June 14
The Sun	June 21
The American Indian	June 28
Costumes of Ladies of the White House	July 5
Transportation	July 12
Meteorites	July 19

	1936
The Human Side of Art	July 26
Mammals	Aug. 2
Power	Aug. 9
The Story of Man in America	Aug. 16
Textiles	Aug. 23
Precious Stones	Aug. 30
Ship Models	Sept. 6
Birds	Sept. 13
Flight (aviation)	Sept. 20
Sculpture	Sept. 27
Insects	Oct. 4
Medicine	Oct. 11
Zoological Park	Oct. 18
Indian Petroglyphs	Oct. 25
Evolution of Life	Nov. 1
Early Man	Nov. 8
What's New in Science	Nov. 15
Color and Life (radiation)	Nov. 22
Musical Instruments	Nov. 29
Coins	Dec. 6
Botany	Dec. 13
Freer Gallery	Dec. 20
Life Story of Smithsonian	Dec. 27
	1937
Maya Indians	Jan. 3
Clocks	Jan. 10
Printing	Jan. 17
Stamps	Jan. 24
Tribes of Africa	Jan. 31
Gold	Feb. 7
Clipper Ships to Modern Liners	Feb. 14
George Washington	Feb. 21
Animals in Armor (mollusks)	Feb. 28
Photography	Mar. 7
Grasses	Mar. 14
Pueblo Indians	Mar. 21
Health	Mar. 28
Early American Inventors	Apr. 4
Uses of Wood	Apr. 11
Scientific Exploration	Apr. 18
Story of Lighting	Apr. 25
Fishes	May 2
Gellatly Art Collection	May 9
Copper	May 16
Birds	May 23
Mound Builders	May 30
Communication	June 6
Mansfield Theatrical Costumes	June 13
Subterranean Caverns	June 20
Indian Arrowheads	June 27

From the beginning the broadcasts were supplemented by brief illustrated articles on the subjects covered, at first issued in mimeographed form, and from January on, printed as a small monthly magazine. Copies were mailed by the Office of Education to those who wrote in to request them, and the demand for the magazine showed a steady increase, as follows:

1937:		1937:	
January	35,000	April	100,000
February	50,000	May	125,000
March	75,000	June	150,000

The success of the series is indicated by the enthusiastic approval of the listeners as voiced in the more than 160,000 letters received. This almost unanimous mail approval is believed to be unique among sustaining programs and is very gratifying to both the Institution and the Office of Education in justifying their efforts toward better educational radio.

I wish again to express here the appreciation of the Institution to the Office of Education and to the National Broadcasting Co. for making available this unsurpassed means of carrying out the Smithsonian's function, "the diffusion of knowledge among men."

WALTER RATHBONE BACON TRAVELING SCHOLARSHIP

The Walter Rathbone Bacon Traveling Scholarship of the Smithsonian Institution was awarded in June 1935 to Dr. Richard E. Blackwelder for studies of the Staphylinidae of the West Indies. In 1935–36 Dr. Blackwelder collected specimens on the islands of Jamaica, Hispaniola, Puerto Rico, St. Thomas, Guadeloupe, Trinidad, Tobago, Grenada, Carriacou, St. Vincent, Barbados, St. Lucia, and Dominica, as previously reported.

During the second year, to June 1937, collections were made on the islands of Montserrat, Antigua, St. Kitts, and St. Croix, and return visits were made to Puerto Rico and Jamaica. It was found to be impracticable to revisit Hispaniola in spite of the importance of that island in the series.

The collections obtained from the 21 months' field work include more than 45,000 staphylinids and 10,000 other Coleoptera. A considerable part of this number were taken by the use of equipment for mass collection which was used on St. Croix and Jamaica. (On the latter island Dr. Blackwelder worked in conjunction with Dr. E. A. Chapin for 5 weeks. The collections were made jointly.)

After finishing the collecting Dr. Blackwelder returned to Washington, where he prepared the staphylinid collections and sorted the specimens to genera and species. A set containing each species found was then prepared to be taken to England, where it will be compared with the types of West Indian and tropical American Staphylinidae in the collections of the British Museum and Dr. Malcolm Cameron.

The extension of the award for a third year made possible the additional 9 months of field work in 1936. Dr. Blackwelder plans to visit Cuba for a week in the fall of 1937 to study the collection of Staphylinidae of Alexander Bierig. The remainder of the year will be occupied with the preparation of a revision of the 500 to 600 species collected or known from the islands.

SIXTH ARTHUR LECTURE

The sixth Arthur lecture, Discoveries from Solar Eclipse Expeditions, by Samuel Alfred Mitchell, director of the Leander McCormick Observatory, University of Virginia, was given in the auditorium of the National Museum on the evening of February 9, 1937. Dr. Mitchell, a leading authority on eclipses, has personally observed nearly all the total solar eclipses of the present century. In his lecture he touched upon the frequency of eclipses and their prediction, facts learned from a study of the gorgeous corona which accompanies a total eclipse, the use of eclipses in the verification of the relativity theory, and many other interesting aspects of this grandest of natural phenomena—an eclipse of the sun. The lecture will be published in full with illustrations in the 1937 Smithsonian Report.

EXPLORATIONS AND FIELD WORK

Field expeditions play an important part in many of the Institution's researches in biology, geology, anthropology, and astrophysics. During the last calendar year 19 expeditions were in the field; the regions visited included, besides 18 States in the United States, Greenland, Alaska, Canada, the Bahamas, Honduras, Guatemala, England, Germany, Holland, and Siam.

Secretary C. G. Abbot continued at Washington his work on perfecting an engine to convert the sun's rays into power. Dr. R. S. Bassler studied the geology of several classic European areas and conducted researches on fossil echinoderms and corals in European museums. E. P. Henderson collected epidote and other minerals in southeastern Alaska. Dr. G. Arthur Cooper studied and collected fossils from the Devonian beds of the midwestern United States. Dr. C. Lewis Gazin conducted a successful search for fossil mammals in New Mexico and Arizona. Dr. Alexander Wetmore studied and collected the birds of the Guatemalan highlands. Watson M. Perrygo and Carleton Lingebach collected birds and mammals in an area in West Virginia hitherto unrepresented in the National Museum's collections. H. G. Deignan made a zoological survey of the little-known easternmost districts of North Siam, journeying through the provinces of Nan and Chiengrai. Capt. Robert A. Bartlett's 1936 Greenland expedition collected for the Institution specimens of the marine plant and animal life in the seas along the east and northeast coast of Greenland. Austin H. Clark continued his exhaustive investigation of the butterfly fauna of Virginia. E. P. Killip collected series of specimens of the flora of the Florida Keys, hitherto poorly represented in the National Herbarium.

Dr. Aleš Hrdlička continued his archeological investigations in Alaska in connection with his study of the origin and early migrations of the American Indian. Henry B. Collins, Jr., conducted archeological investigations in the vicinity of Bering Strait, Alaska, to coordinate the results of his previous work at St. Lawrence Island and at Barrow. Herbert W. Krieger made an archeological reconnaissance of the Bahama Islands and excavated prehistoric village sites on five of the larger islands. Dr. Frank H. H. Roberts, Jr., continued his investigations of the Folsom complex, mainly at the Lindenmeier site in northern Colorado. Dr. William Duncan Strong led an archeological expedition to northwestern Honduras, excavating sites on the Ulua River and at Lake Yojoa which gave a stratigraphic section from the historic occupation at Naco, through the various polychrome horizons on the Ulua and at Lake Yojoa, and down to the Playa de los Muertos culture which preceded the Maya culture. J. N. B. Hewitt continued his studies of the League of the Iroquois in New York State and Ontario, Canada. Dr. Julian H. Steward made an ethnological reconnaissance of the desert Shoshoni of southern Idaho, northern Utah, and a part of eastern Nevada.

PUBLICATIONS

The "diffusion of knowledge", one of the Institution's primary functions, is accomplished chiefly through its several series of publications. As is to be expected from the nature of the Institution's scientific work, the large majority of its publications are technical in character, presenting the results of researches in astrophysics, radiation, geology, biology, and anthropology. The Smithsonian annual report, however, is intended primarily for the layman, for in it are presented each year a series of understandable articles written by recognized authorities, which together constitute a survey of advances and interesting developments in nearly all branches of science. The wider diffusion of knowledge is accomplished by a system of news releases furnished to more than 300 newspapers and press services describing in popular form the Institution's researches, expeditions, and publications; and recently by a weekly radio program dramatizing the work and exhibits of the Institution put on the air through the cooperation of the Office of Education, the Works Progress Administration, the National Broadcasting Co., and the Institution's editorial office.

Of the 80 volumes and pamphlets published during the year, 46 were issued by the Smithsonian proper, 32 by the National Museum, and 2 by the Bureau of American Ethnology. Details of these various publications are given in the report of the editor, appendix 10. The total number of copies of publications distributed was 144,817.

LIBRARY

The Smithsonian library comprises 10 major and 35 minor units, which together contain a total of 876,522 volumes, pamphlets, and charts. The new accessions for the year numbered 11,469, most of these coming in exchange for the publications of the Institution and its branches. The library received many gifts during the year, outstanding among which was the botanical library of the late Dr. Frederick V. Coville, numbering 4,500 items, presented by Mrs. Coville. The routine work of the staff included cataloging 6,766 publications, preparing and filing 28,967 cards, entering 24,212 periodicals, and making 10,995 loans, of which 196 were to libraries outside the Smithsonian system. In addition to considerable work on the union catalog, much time was spent on the preparation of periodicals for binding, and a total of 3,803 volumes were bound. This unusually large amount of binding was made possible by the deficiency appropriation of $12,000 approved toward the close of 1935. There still remain thousands of volumes in urgent need of binding to prevent loss of parts, many of which would be very difficult to replace.

Respectfully submitted.

C. G. Abbot, *Secretary.*

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operation of the United States National Museum for the fiscal year ended June 30, 1937:

Funds provided for the maintenance of the National Museum for the year totaled $763,970. This was a net increase of $3,228 over the previous year, but since $25,000 was expended last year for the purchase of the airplane *Winnie Mae* for the aeronautical collections, the actual increase was $28,228 for purposes of maintenance and operation, printing and binding, and preservation of collections.

COLLECTIONS

Additions to the Museum collections during the year, coming mostly as gifts from individuals or from expeditions sponsored by the Smithsonian Institution, comprised the usual wide variety of material in all departments. A total of 361,951 specimens were received in 1,800 separate accessions and distributed as follows: Anthropology, 1,790; biology, 292,250; geology, 62,757; arts and industries, 3,180; and history, 1,974. These accessions are all listed in detail in the full report on the Museum, printed as a separate pamphlet, but the more important are summarized as follows:

Anthropology.—Important archeological material included two Guatemalan vases—a replica of a stuccoed vase from Uaxactun and an original Maya vase from Lake Petén. Alaska was represented by 52 bone and stone artifacts from the Rat Islands, Aleutians, and by an ivory harpoon socket from St. Lawrence Island belonging to the Old Bering Sea culture. From South Africa came 29 Neolithic stone artifacts and potsherds. Other valuable specimens came from the Bull Creek archeological site in Georgia; the Black Mountains, Ariz.; and the Rappahannock River, Va.

Of special interest among the ethnological material received were unusual specimens presented by Mrs. Charles D. Walcott representing the Kiowa Indians of Oklahoma, the Navahos, the Jivaros of South America, and from Hawaii. Other accessions include Madagascan woven fabrics and basketry and Kashmir copper and silver objects collected nearly 50 years ago by the late Dr. W. L. Abbott; baskets, idols, combs, figurines, and other objects from Dahomey, Cameroons, Nigeria, Belgian Congo, Portuguese East Africa, and Southern Rhodesia; jewelry from Tibet; a collection of ethnological material from Guatemala; and costumes and ceremonials of the Blackfeet and the Indiana Algonkians. Nearly 100 specimens were received in the division of ceramics, 57 in musical instruments, and 43 in period art and textiles.

The 600 specimens added to the physical anthropology collection came mostly from Alaska, as a result of the field work of the curator, and from Florida, as a result of Smithsonian-C. W. A. projects. Another lot of skeletal material came from three ossuaries in Maryland and the District of Columbia.

Biology.—Nearly 300,000 biological specimens a year now come to the Museum, and the total now exceeds 12,000,000. Of those received during the past year the following are outstanding: An unusually large number of mammals from Panama, West Virginia, Siam, Japan, Formosa, and the Philippine Islands, and Dr. Ira N. Gabrielson's private collection, numbering 855 specimens, which were transferred from the Biological Survey; more than 1,100 skins and skeletons of birds from Siam, 360 from Guatemala, and 1,000 from West Virginia; types and paratypes of many new forms of reptiles and amphibians, both North and South American; 90 large fishes from Lower California, over 1,700 fishes collected on the Smithsonian-Roebling expedition, over 800 Siamese fishes, nearly 6,900 fishes deposited in the Museum by the University of Washington, and over 4,400 fishes from Maryland, Virginia, and miscellaneous localities; 60,000 insects transferred from the Bureau of Entomology and Plant Quarantine, 60,000 more collected in the West Indies by Drs. E. A. Chapin and R. E. Blackwelder, and the J. F. G. Clarke collection of 10,000 Lepidoptera, mostly from the Pacific Northwest; over 15,000 marine invertebrates chiefly from various expeditions cooperating with the Smithsonian; 108,000 mollusks from many sources, including 10,000 from Siberia, from the Walter Rathbone Bacon Traveling Scholarship, and 11,000 purchased through the Frances Lea Chamberlain fund; and more than 45,000 plants, about a fourth of which were transferred from the United States Bureau of Plant Industry.

Geology.—Income from several Smithsonian funds brought valuable mineralogical specimens. Through the Roebling fund, crystal groups and mineral examples from many localities; through the Canfield fund, minerals from the copper mines at Tsumeb, Southwest Africa, and crystals of various kinds that make up an unusually colorful exhibit; and through the Frances Lea Chamberlain fund, four rare gem stones. There were also many donated specimens of rare crystals, ores, and other minerals that notably enhance the Museum's collections.

Additions to the meteorite collection were obtained largely through the Roebling fund. The total number of distinct meteoritic falls represented in the Museum was increased from 606 to 635 during the year. The new material came from Chile, Australia, Canada, and the United States. Outstanding additions to the rock collections were from Easter Island, Mexico, the Carolinas, Arkansas, Wyoming, and Colorado.

In the field of stratigraphic paleontology most of the year's accessions were obtained by members of the staff: 30,000 Devonian invertebrates collected by Dr. G. A. Cooper and P. E. Cloud in the Eastern States and 20,000 Tertiary and Cretaceous invertebrates obtained by Dr. R. S. Bassler in Europe. Exchanges arranged with other museums and with individuals brought in many other specimens from Africa, Australia, Austria, Bohemia, England, France, Hawaiian Islands, Italy, and the United States, representing various geologic periods and formations and many classes of fossil animals and plants.

About 625 fossil vertebrates were added to the paleontological series. These included 600 Paleocene and Pliocene mammals collected by Dr. C. L. Gazin and party in New Mexico and Arizona last year, a mountable skeleton of the giant sloth *Mylodon harlani* from the Rancho La Brea deposits in California, a mounted skeleton of the antilocaprid *Merycodus* from the Miocene of Montana, an excellently preserved extinct musk-ox skull (*Symbos cavifrons*) from the Pleistocene of Indiana, a nearly complete fossil turtle (*Aspideretes superstei*) from the Paskapoo formation of Alberta, and two eggs of *Struthio andersoni*, an extinct ostrich, from China.

Arts and industries.—The outstanding accession in aeronautics was the gondola of the stratosphere balloon *Explorer II*, in which Capts. A. S. Stevens and O. A. Anderson in 1935 established the present altitude record of 72,395 feet for a manned balloon, presented by the National Geographic Society. The collection of scale models of aircraft was increased by 12 of commercial airmail planes (made for the Great Lakes Exposition), 4 of current Navy types, 2 of World War German planes, and several others including the Stinson Detroiter and Lockhead Vega used by George Hubert Wilkins in his 1927 and 1928 Arctic flights. Mrs. Wiley Post presented instruments that were used on the *Winnie Mae*. There were also accessioned various objects connected with the historic flights or aircraft of Calbraith P. Rodgers (1911), Maj. Russell L. Maughan (1924), John Moisant (1910), and Alberto Santos-Dumont.

An interesting accession in watercraft is a collection relating to the life and work of John W. Griffiths, naval architect, writer, and editor, whose ships the *Rainbow*, 1845, and the *Sea Witch*, 1846, were the first of the famous American clippers. A number of half-models, many as a result of the Historic American Merchant Marine Survey work, also were added. For the transportation group came the first Franklin automobile (no. 3) to leave the factory in 1902, the oldest existing example of that car; a gig phaeton of about 1840; and a fine operating scale model of the Baltimore & Ohio Railroad's Royal Blue train. Many objects of historical radio equipment, phonographs, typewriters, calculating machines, clocks, tools, and electrical devices continued to come in, as well as over 2,000 specimens pertaining to textiles, organic chemistry, wood technology, history of agriculture, and medicine, and about 500 photographs, prints, drawings, engravings, books, tools, and other material relating to the graphic arts.

History.—Nearly 2,000 objects of historic and antiquarian interest and value were received, many of them pertaining to the lives and public careers of eminent Americans and other historic characters, such as Lafayette, Benjamin Franklin, Napoleon I, and President Benjamin Harrison. The numismatic collection was increased by 321 coins, including an important series of United States commemorative half-dollars; and the philatelic collection by 1,384 stamps, most of which were specimens of current foreign postage stamps transferred from the Post Office Department.

EXPLORATIONS AND FIELD WORK

The scientific explorations of the year were financed mainly by grants from the invested funds of the Smithsonian Institution or by the assistance of friends of the Museum.

Anthropology.—Henry B. Collins, Jr., assistant curator of ethnology, in October 1936 terminated his archeological investigations on St. Lawrence Island, Alaska, conducted under the joint auspices of the National Geographic Society and the Smithsonian Institution. Previous work on St. Lawrence Island and at Point Barrow had revealed the existence of an ancient but highly developed Eskimo culture, with intermediate stages between it and the modern Eskimo. One objective of the expedition was to search for pre-Eskimo remains in the vicinity of Bering Strait, where man may first have entered the American Continent. Mr. Collins and his assistants, James A. Ford and Harrison Prindle, obtained definite evidence on the sequence of prehistoric Eskimo cultures, but nowhere did they find traces of human occupancy antedating that of the Eskimo.

From October to February, Herbert W. Krieger, curator of ethnology, conducted archeological investigations in the Bahaman Archipelago under a Smithsonian grant. He excavated kitchen middens and burials on Long Island, Inagua, and New Providence Island and uncovered data pointing to a close cultural contact between the Lucayan Indians of the Bahamas and the Arawak of Hispaniola and to the tribal migration of the Lucayans at a comparatively recent date from the island of Hispaniola.

Dr. Waldo R. Wedel, assistant curator of archeology, devoted some time to the supervision of excavations at an Indian village site near Seneca, Montgomery County, Md. On May 15 he left to conduct a general archeological survey of northeastern Kansas and to excavate part of an old Kansa site near Kansas City; he was still in the field as the year closed.

Dr. Aleš Hrdlička, curator of physical anthropology, assisted by four students, during July and August 1936 investigated sites on the Aleutian Islands, in continuation of his Alaskan researches. He unearthed an important burial cave on Kagamil Island, transportation being furnished through the cooperation of the United States Coast Guard. In May 1937 he returned again to the Aleutians to continue the work.

Dr. T. Dale Stewart, assistant curator of physical anthropology, visited Indian-burial sites along the Potomac River, assisting private investigators. Also, with the help of Dr. Wedel, he excavated two ossuaries at Bolling Field, D. C.

Biology.—Gerrit S. Miller, curator of mammals, assisted by Charles M. Wheeler, spent 3 months in Panama making collections for the Museum. With Corozal, C. Z., as a base, he worked over most of the Canal Zone from Gatun and Barro Colorado to the Pacific coast and along the national highway of Panama, with side trips to the Pearl Islands, Taboga Islands, and the Indio River. The material brought back includes about 450 mammals, 150 birds, 150 reptiles and amphibians, and 400 plants, as well as fishes, shells, marine invertebrates, and Indian artifacts.

Dr. Remington Kellogg, assistant curator of mammals, was one of the three delegates to represent the United States at a whaling conference, which convened in London on May 24, 1937, on invitation of the British Government.

H. G. Diegnan continued collecting in Siam and sent three large shipments of birds and other material to the Museum. Dr. Alexander Wetmore collected birds in the highlands of Guatemala in the fall of 1936 and brought back a series of valuable specimens. W. M. Perrygo and Carleton Lingebach collected birds during the year in West Virginia and Tennessee. Dr. David C. Graham continued his work in western China, forwarding collections mainly of birds and insects.

Dr. Leonard P. Schultz, assistant curator of fishes, and E. D. Reid, aid, made several successful collecting excursions into Virginia as part of a survey of the fresh-water fish fauna of that State.

Dr. E. A. Chapin, curator of insects, spent about 6 weeks in Jamaica, where, after examining entomological collections in Habana, he collected insects on the island in conjunction with Dr. and Mrs. Richard E. Blackwelder. Several families of beetles, hitherto unknown from the island, were taken, as well as many species recognized as new to science. They also took over a thousand specimens representing seven species of the family Dryopidae, previously recorded as nonexistent on the island. A new and interesting coccinellid of the genus *Psyllobora* was found feeding on a mold growing upon the leaves of beach-grape (*Coccoloba uvifera*), and at least two undescribed species of Scarabaeidae have been recognized in the material collected.

Dr. Waldo L. Schmitt, curator of marine invertebrates, was naturalist on the Smithsonian-Hartford expedition to the West Indies, traveling on one of the last of the square-rigged ships afloat, the *Joseph Conrad*, through invitation of the owner, G. Huntington Hartford, and accompanied by Robert G. Lunz, of the Charleston Museum, as assistant. The party began work on March 15 at Nassau in the Bahamas and in 2 months traveled as far south as Barbados. In all they covered about 4,500 miles, making 19 stops for collecting on 15 different islands. The expedition, aided greatly by the excellent equipment provided by Mr. Hartford, was eminently successful. More than 4,000 specimens of marine invetebrates were obtained, chiefly Crustacea, but including also sponges, coelenterates, annelids, mollusks, echinoderms, and lower chordates. Vertebrate material brought back included fishes and two adult porpoises, in one of which was found an embryo.

Dr. Paul Bartsch, curator of mollusks, was a member of the Smithsonian-Roebling expedition to the Caribbean Sea and the Gulf of Mexico in the spring of 1937. Traveling on Donald Roebling's yacht *Iorano*, the party worked from Habana, Cuba, around the western end of the island and along the south coast as far as Guantanamo. Extensive marine collections were obtained over a wide area. These include material previously poorly represented in the Museum, which is now being studied and rapidly identified.

Geology.—Sponsored by the Smithsonian Institution, Dr. R. S. Bassler, head curator of geology, spent the first 3 months of the fiscal year in geological studies of several classic European areas and in researches on echinoderms and other fossils in English, German, and Dutch museums. He completed studies on several groups of Paleozoic corals and sponges, prepared about 600 casts of Upper Paleozoic crinoid types, collected Tertiary fossils from the Paris, Vienna, and London Basins, and visited the Devonian area of Germany and Czechoslovakia.

Under the auspices of the Roebling fund, E. P. Henderson, assistant curator of physical and chemical geology, spent several months on Prince of Wales Island, Alaska, for the purpose of collecting specimens of epidote and other minerals for which this locality is noted. With the aid of his assistants, Arthur Montgomery, Edwin Over, and C. B. Ferguson, he collected hundreds of fine crystals of epidote, thousands of garnets, and many miscellaneous minerals. In May 1937 Mr. Henderson left to attend the Seventeenth International Geological Congress at Moscow.

In the summer of 1936, Dr. G. A. Cooper, assistant curator of stratigraphic paleontology, with Preston E. Cloud as field assistant, visited Middle Devonian localities in the Middle West to collect fossils and study the Middle Devonian rocks. In June 1937 these two men pursued further field work on the Middle Devonian rocks of Michigan, New York, and Ontario.

Dr. E. O. Ulrich, associate in paleontology, accompanied by R. D. Mesler, of the Geological Survey, collected fossils and studied Lower Ordovician stratigraphy in Arkansas and nearby States.

C. W. Gilmore, curator of vertebrate paleontology, with Dr. Remington Kellogg, made two short trips to the Chesapeake Bay region to collect cetacean specimens, including several porpoise skulls, previously located by Dr. W. F. Foshag.

Dr. C. Lewis Gazin, assistant curator of vertebrate paleontology, under funds provided by the Smithsonian Institution, conducted an expedition to the San Juan Basin, N. Mex., during the summer of 1936 to explore the Eocene Wasatch and the Puerco and Torrejon formations of the Paleocene for fossil mammal remains. Besides Dr. Gazin, the party included G. F. Sternberg and Harold Shepherd. They were successful in gathering a representation of the important faunas from these classic early Tertiary horizons, about 500 determinable specimens being collected from the Paleocene alone. Later in the season they went to Arizona and explored the Gila and San Pedro Valleys for fossils.

Dr. R. Lee Collins, of Bryn Mawr, was given a small grant by the Smithsonian Institution for work in the Miocene deposits along Chesapeake Bay, during the course of which he collected a number of cetacean specimens, parts of a sirenian, and two bird bones.

MISCELLANEOUS

Visitors.—For the first time, the number of visitors to the various Museum buildings exceeded the 2 million mark, the total for the year being 2,288,532, which is 314,859 more than the previous year. The 351,219 visitors during August 1936 is the largest number ever recorded for a single month. The attendance in the four Museum buildings was recorded as follows: Smithsonian Building, 364,057; Arts and Industries Building, 1,050,388; Natural History Building, 702,657; Aircraft Building, 171,430.

Publications and printing.—The sum of $22,000 was available during the year for printing the Museum Annual Report, Bulletins, and Proceedings, an increase of $17,950 over the previous year, and a corresponding increase in volume of publication was reflected. Thirty-three publications were issued—the Annual Report, 1 volume of Proceedings (completed), 2 Bulletins, and 29 Proceedings separates. The two Bulletins issued were: No. 153, part 2, "Birds Collected by the Childs Frick Expedition to Ethiopia and Kenya Colony: Passeres", by Dr. Herbert Friedmann; and no. 167, "Life Histories of North American Birds of Prey: Part 1, Order Falconiformes", by Arthur Cleveland Bent, the tenth volume in this series of life histories of North American birds. The total number of octavo pages printed was 1,604; and of plates, 135. Volumes and separates distributed during the year to libraries and individuals throughout the world aggregated 68,822, more than twice as many as last year.

An important step in the advance of Museum efficiency was the thorough overhauling and equipping of the Museum's Branch Printing Office early in the year. Through the generous cooperation of the Public Printer, a reconditioned and fully equipped linotype machine was installed by the Government Printing Office, together with new type faces suitable for the printing of Museum labels. As a direct result of this new equipment, the labeling and job-printing work of the Museum is practically up to date for the first time in many years.

Assistance from work relief agencies.—The Museum profited much by the continued assignment of workers from the Works Progress Administration of the District of Columbia. The number of such workers increased from 66 at the beginning of the year to 88 at the end, and the work totaled 89,419 man-hours, covering the following tasks: Checking, labeling, and repairing library material; preparing drawings and photographs; typing; arranging, cataloging, labeling, mounting, and numbering specimens; model making; translating; work on plaster casts; and drafting.

Special exhibitions.—Sixteen special exhibitions were held during the year under the auspices of various scientific, educational, and Government agencies, such as the Works Progress Administration, Third World Power Conference, Association of Federal Architects, and the District of Columbia Federation of Women's Clubs.

The division of graphic arts featured 18 special exhibits—9 in graphic arts and 9 in photography.

Changes in organization and staff.—No major change in administrative organization occurred during the year and but few changes in the scientific staff. The designation of the carpenter shop was changed in April to cabinet shop, and steps were taken for the appointment of an assistant foreman of the shop to be directly charged with its building-repair activities.

Eight persons were retired for age or disability, as follows—through age: Frank H. Cole, assistant mechanical superintendent in charge of the carpenter shop, on February 28, 1937, with over 39 years of service; William F. Wicks, guard, on May 31, 1937, with 10 years of service; Minor R. Stonnell, tinner's helper, on June 30, 1937, with nearly 27 years of service; Mrs. Hanorah Downey, attendant, on October 31, 1936, with nearly 25 years of service; and Mrs. Elizabeth Merritt, charwoman, on November 30, 1936, with nearly 22 years of service. Through disability: William Henry Goldsmith, foreman of laborers, on April 30, 1937, with 41 years of service (Mr. Goldsmith died on May 4, 1937, 4 days after his retirement); Mrs. Elizabeth E. Dorsey, foreman of charwomen, on June 15, 1937; and Mrs. Gertrude Green, charwoman, on May 6, 1937.

Dr. George S. Myers resigned as assistant curator of fishes on September 15, 1936, to accept an appointment at Stanford University. Dr. Leonard P. Schultz, of the University of Washington, was appointed to succeed Dr. Myers, December 31, 1936. Dr. Waldo R. Wedel was appointed assistant curator of archeology on August 15, 1936. The designation of Dr. William R. Maxon as head of the division of plants (the National Herbarium) was changed from associate curator to curator on February 1, 1937. Mrs. Agnes F. Chase, senior botanist in the United States Bureau of Plant Industry, long associated with the late Dr. A. S. Hitchcock, was given honorary appointment on February 15, 1937, as custodian of the section of grasses in the Museum.

Other additions to and changes on the staff during the year included the appointments of Henry Kaskowitz as junior scientific aid in the division of vertebrate paleontology on August 1, 1936, and of Andreas J. Andrews as scientific aid in the department of anthropology on May 14, 1937; the reallocation of Mrs. Bertha T. Carwithen to senior clerk, assistant personnel officer, on February 16, 1937; the appointment of Owen F. Croggon, senior mechanic (senior cabinetmaker) on July 1, 1936, to fill a new position included in the appropriations for the year; the advancement of John H. Chance to assistant engineer, on September 19, 1936; of Ernest Desantis from guard to principal guard (sergeant of watch) on November 1, 1936, and of John J. Queeney from guard to foreman of laborers on June 19, 1937.

On January 1, 1937, Norman H. Boss, chief preparator, invertebrate paleontology, returned to duty from temporary detail to the Texas Centennial Exposition, at Dallas, and on June 16, 1937, he was detailed as exhibit supervisor for the Smithsonian for the Greater Texas and Pan American Exposition at Dallas.

Necrology.—Through death the Museum lost during the year three employees from its active roll: William H. Vanneman, principal guard, on August 20, 1936, after 39 years of service; Frank M. Cheeks, laborer, on January 3, 1937, after 27 years of service; and William C. McKinnon, guard, on February 13, 1937, after 13 years of service. From its list of honorary workers the Museum lost by death on January 9, 1937, Dr. Frederick Vernon Coville, honorary curator of plants since March 28, 1893, associated with the division of plants for many years, and one of those deeply interested always in furthering the Museum's botanical work.

Respectfully submitted.

ALEXANDER WETMORE,
Assistant Secretary.

DR. CHARLES G. ABBOT,
Secretary, *Smithsonian Institution*.

APPENDIX 2

REPORT ON THE NATIONAL COLLECTION OF FINE ARTS

Sir: I have the honor to submit the following report on the activities of the National Collection of Fine Arts for the fiscal year ended June 30, 1937:

For nearly 8 months of the fiscal year, this bureau of the Smithsonian Institution carried the name "National Gallery of Art", but this was changed by an Act of Congress, approved by the President on March 24, 1937, to "National Collection of Fine Arts", and the old name was assigned to the new Smithsonian bureau created as the result of Andrew W. Mellon's gift to the Nation of his unexcelled art collection and funds to erect a splendid building to house it.

A new system of lighting was installed over gallery 3, which produces a pleasing soft light and also does away with the lighting fixtures and gives a ceiling to the gallery. This also made possible the installation of four stained glass windows, two by John La Farge and two by William Willet.

Miss Louise A. Rosenbusch, who had been connected with the Smithsonian Institution for 44 years and had served as Recorder of the National Gallery of Art since it was made a separate unit in 1920, was retired on November 30, 1936.

Visitors to the office concerning art matters numbered 111 during the last 5 months.

APPROPRIATIONS

For the administration of the National Collection of Fine Arts by the Smithsonian Institution, including compensation of necessary employees, purchase of books of reference and periodicals, traveling expenses, uniforms for guards, and necessary incidental expenses, $34,275.00 was appropriated, of which $16,893.29 was expended for the care and maintenance of the Freer Gallery of Art, a unit of the National Collection of Fine Arts.

THE NATIONAL GALLERY OF ART COMMISSION

The sixteenth annual meeting of the National Gallery of Art Commission was held on December 8, 1936. The members met at 10:30 at the National Gallery of Art, where, as the advisory committee on the acceptance of works of art which had been submitted during the year, they accepted the following:

Two lithographs: "Drying Fish Nets, Charlevoix" and "Edge of the Canyon", by Grace Neville Carrothers. Gift of the artist in the name of her son, Edgar M. Carrothers, Jr.

Bronze relief portrait of Daniel Chester French (1850–1935), by Evelyn Beatrice Longman (Batchelder). Gift of Mrs. E. B. L. Batchelder, of Windsor, Conn. (Accepted for the National Portrait Gallery.)

A water color by Samuel Prout (1785–1852). Gift of Mrs. John T. Devine, of Washington, D. C. (The legal status of this gift is in the hands of the executor and has not been decided to date.)

A collection of 197 intaglio prints, by members of the Chicago Society of Etchers, to be added to the 497 intaglio prints given last year. Gift of the Chicago Society of Etchers.

Two line engravings "The Old Tinker" and "The Sister", and two pencil drawings both entitled "Study for 'The Hedger'", by Stanley Anderson. Gift of the artist.

The following two paintings, purchased by the Council of the National Academy of Design from the fund provided by the Henry Ward Ranger bequest were recalled and claimed, according to the terms of the will: "Central Park and the Plaza", by William A. Coffin (1855–1925) and "Cliffs of the Upper Colorado River, Wyoming Territory", by Thomas Moran (1837–1926).

A pair of stained glass windows, "Peacock and Peony", by John LaFarge (1835–1910). Gift of Henry LaFarge.

An oil painting entitled "Dressing for the Rehearsal", by Seymour J. Guy, N. A. (1824–1910). Gift of Miss Jennie A. Guy, the artist's daughter.

(In 1928, a Portrait of George Inness, by F. C. Courter, offered as a gift by an anonymous donor, was accepted by the Commission. It was actually received in May 1937, but as a gift of August Franzen.)

The members then proceeded to the Smithsonian Building, where the annual meeting was called to order by the chairman, Mr. Borie. The members present were: Charles L. Borie, Jr., chairman; Frank Jewett Mather, Jr., vice-chairman; Dr. Charles G. Abbot (ex officio), secretary; and Herbert Adams, Frederick P. Keppel, John E. Lodge, Paul Manship, George B. McClellan, Charles Moore, Edward W. Redfield, Edmund C. Tarbell, and Mahonri Young. Ruel P. Tolman, curator of the division of graphic arts in the United States National Museum and acting director of the National Collection of Fine Arts, was also present.

Mr. Moore, chairman of the executive committee, stated that Mr. Mellon had had tentative plans for the National Gallery of Art building prepared by John Russell Pope. These plans, as well as the present status of the National Portrait Gallery, were discussed.

The Commission recommended to the Board of Regents the nomination of Dr. George Harold Edgell, director of the Museum of Fine Arts, Boston, to succeed Mr. Gest, deceased.

The Commission recommended to the Board of Regents the reelection for the succeeding term of 4 years of the following members:

John E. Lodge, Andrew W. Mellon, Edward W. Redfield, and Paul Manship.

The following officers were elected for the ensuing year: Charles L. Borie, Jr., chairman; Frank Jewett Mather, Jr., vice chairman; and Dr. Charles G. Abbot, secretary; as well as the members of the executive committee—Charles Moore, Herbert Adams, and George B. McClellan (Charles L. Borie, Jr., as chairman of the Commission, and Dr. Charles G. Abbot, as secretary of the Commission, are ex officio members of the executive committee).

The following minute was adopted to express the policy of the Commission in connection with its action in accepting or rejecting Ranger fund paintings:

> In reaching a decision as to the acceptance of paintings purchased from the Ranger fund, it was the sense of the Commission that the artistic quality of the painting in question should not necessarily be the only factor to be taken into consideration. The presence of other examples of the artist's work in the national collection, for example, may properly be taken into consideration, or the desirability of a wide distribution of these paintings in the permanent collections of the country.

SPECIAL MEETINGS

In accordance with the request of the chairman, Mr. Borie, the Commission met at the Smithsonian Institution April 6, 1937, for the purpose of affording the members an opportunity of discussing the acceptance by Congress of the Mellon gift under the title of the National Gallery of Art, and the project for the proposed Smithsonian Gallery of Art.

The Commission's attention was also called to the desire of Mrs. Mabel Johnson Langhorne, daughter of the donor of the Ralph Cross Johnson collection of old masters, to name the Smithsonian Institution in her will to receive certain pictures left to her by her father, if the Institution thought them worthy of acceptance for the national collection.

After the adjournment of the meeting the members inspected the Mellon and Langhorne collections.

On May 11, 1937, a committee of three, appointed by Dr. Abbot and Mr. Borie, consisting of Mr. Redfield, Mr. Tarbell, and Mr. Young, met at the home of Mrs. Langhorne to select the paintings which eventually will come to the Institution to be closely associated with the Ralph Cross Johnson gift. Almost every painting was considered of such high quality that it would be a valuable addition to the collection.

THE CATHERINE WALDEN MYER FUND

Two miniatures were acquired from the fund established through the bequest of the late Catherine Walden Myer, "for the purchase of first-class works of art for the use and benefit of the National Gallery of Art", as follows: "Portrait of Charles Boynton Darling" and "Portrait of Elizabeth Ellis Darling", by unknown artist; from Laurence B. Darling, New York, N. Y.

This endowment, although small, has in 5 years made possible the purchase of 11 first-class miniatures, illustrating how a small endowment can be used to build up over a period of years an important collection.

DEPOSITS

Portrait of Dr. Leonhard Stejneger, Head Curator of the Department of Biology, United States National Museum, by Bjorn P. Egeli, presented to the Smithsonian Institution by Dr. Stejneger's friends on his birthday, October 30, 1936, was deposited in the Gallery by the Smithsonian Institution.

Portrait bust in bronze of Lord Kelvin (William Thomson 1824–1907), British physicist, by Herbert Hampton, given by the Kelvinator Co. to the English Speaking Union for presentation to the Smithsonian Institution, and presented by the British Embassy through the American Branch of the Union, October 9, 1936, was deposited in the Gallery by the Smithsonian Institution.

LOANS ACCEPTED

A stained glass window, "Consumatum Est", designed and executed by William Willet (1869–1921) in 1906, which won the contract for a sanctuary window in the United States Military Chapel at West Point; also a pair of small stained glass windows, "Dante" and "Beatrice", by William Willet. Lent by Mrs. William Willet, of Philadelphia, Pa.

LOANS MADE

Two portrait drawings in red chalk of Victor Chapman and Norman Prince, by John Elliott, were lent to the Art Association of Newport for exhibition at the Tercentenary Retrospective Exhibition, Newport, R. I., from July 25 to August 16, 1936. (Returned Aug. 20, 1936.)

The painting, "High Cliff, Coast of Maine", by Winslow Homer, was lent to the Whitney Museum of American Art, New York, N. Y., for the Winslow Homer Exhibition which was held from December 15, 1936, to January 15, 1937. (This was sent directly to the Carnegie Institute at the close of the exhibition.)

Two paintings by Winslow Homer, entitled "High Cliff, Coast of Maine" and "The Visit of the Mistress", were lent to The Carnegie Institute, Pittsburgh, Pa., for the Winslow Homer Memorial Exhibition held January 28 through March 7, 1937. (These were returned Mar. 13 and 19, 1937, respectively.)

Through the cooperation of Miss Leila Mechlin, director of the Southern Art Projects, 16 paintings were lent to the New Mint Museum of Art, Charlotte, N. C., for its special inaugural exhibition from October 22 to December 31, 1936, as follows:

June, by John Alexander.
Caresse Infantine, by Mary Cassatt.
Summer, by Charles H. Davis.
Portrait Sketch of Walter Shirlaw, by Frank Duveneck.
Illusions, by Henry B. Fuller.
Sundown, by George Inness.
An Interlude, by Wm. Sergeant Kendall.
Visit of Nicodemus to Christ, by John La Farge.
Three Trees, by W. L. Lathrop.
A Family of Birches, by Willard L. Metcalf.
Bradbury's Mill Pond No. 2, by Henry W. Ranger.
The Torrent, by John H. Twachtman.
November, by Dwight Tryon.
The Cup of Death, by Elihu Vedder.
A Gentlewoman, by J. Alden Weir.
Autumn at Arkville, by Alexander H. Wyant.

Seven of the above paintings were returned January 5, 1937. The following nine paintings were shipped directly from the New Mint Museum of Art at the close of the exhibition to the University of North Carolina, Chapel Hill, N. C., for an exhibition from January 15 to February 20, 1937; the paintings were then forwarded to Savannah, Ga., where they were exhibited at the Telfair Academy of Arts and Sciences from March 7 to 28, 1937. (They were returned Apr. 2, 1937.)

Portrait Sketch of Walter Shirlaw, by Frank Duveneck.
Bradbury's Mill Pond No. 2, by Henry W. Ranger.
The Torrent, by John H. Twachtman.
A Gentlewoman, by J. Alden Weir.
Autumn at Arkville, by Alexander H. Wyant.
Visit of Nicodemus to Christ, by John La Farge.
A Family of Birches, by Willard L. Metcalf.
Caresse Infantine, by Mary Cassatt.
Three Trees, by W. L. Lathrop.

Three paintings, by undetermined artists, were lent December 17, 1936, to the Public Library of the District of Columbia, as follows:

Madonna with Halo of Stars.
Adoration of the Christ Child.
The Christ Child with Cross and Torch.

An oil painting, "Mother Love", by Charles F. Naegele, was lent March 10, 1937, to the High Museum of Art, Atlanta, Ga. (It was returned May 5, 1937.)

A bronze statue of Lincoln, by Augustus Saint Gaudens, was lent, with the consent of the owners, the Estate of Mrs. John Hay, to the Great Lakes Exposition, Cleveland, Ohio, for exhibition from May 29 to September 6, 1937.

LOANS RETURNED

The painting entitled "The Moose Chase", by George de Forest Brush, lent through the Carnegie Public Library at Fort Worth, Tex., to the Fort Worth Frontier Centennial Exhibition, held at Forth Worth, was returned November 20, 1936.

Two small bronzes by Edward Kemeys, entitled "Bear" and "Coyote", lent with permission of their owner, Mr. William Kemeys, to the Dallas Museum of Fine Arts for exhibition at the Texas Centennial Exposition, were returned December 7, 1936.

The painting "Fired On", by Frederic Remington, and the "Portrait of Premier Georges Clemenceau", by Cecilia Beaux, lent to The Dallas Museum of Fine Arts for exhibition at the Texas Centennial Exposition, were returned December 8, 1936.

The following five paintings, lent to the Public Library of the District of Columbia on February 28, 1936, were returned December 17, 1936:

Portrait of Henry B. Fuller, by George Fuller.
Portrait of Jessie J. Burge, by Abbott H. Thayer.
Portrait of Wyatt Eaton, by J. Alden Weir.
The Visit of the Mistress, by Winslow Homer.
Moonlight, by Albert P. Ryder.

The "Portrait Sketch of Walter Shirlaw", by Frank Duveneck, lent to the Cincinnati Museum of Art, Cincinnati, Ohio, for an exhibition of the works of Duveneck, was returned September 15, 1936.

WITHDRAWALS BY OWNERS

Two portraits in pastel by James Sharples (1751–1811) of Gen. James Miles Hughes, original member of the Society of the Cincinnati, and Mrs. James Miles Hughes, his wife, lent in 1932; withdrawn by their owner, Madame Florian Vurpillot on December 15, 1936.

One oil painting entitled "A Farnese Investiture", lent in 1928; withdrawn by the owner, Mrs. Estelle Bakewell-Green on March 2, 1937.

A reproduction in silver, made in England about 1850, of a silver-gilt wine pitcher, attributed to Benvenuto Cellini, lent in 1933; withdrawn by the owner, Capt. Frank O. Ferris, on April 20, 1937.

A painting entitled "Adoration of the Kings", by B. Van Orley (1493–1542); withdrawn by the owner, Mrs. Marshall Langhorne, on May 3, 1937.

A bronze bust of Dr. John Wesley Hill, by Joseph Anthony Atchison, lent by the sculptor in 1930; withdrawn by Mr. Wade H. Cooper, the owner, on May 5, 1937.

THE HENRY WARD RANGER FUND PURCHASES

Since it is a provision of the Ranger bequest that paintings purchased from the fund and assigned to American art institutions may be claimed by the National Gallery during the 5-year period beginning 10 years after the death of the artist represented, five paintings were recalled for action of the National Gallery of Art Commission at its meeting December 8, 1936.

Two paintings were accepted by the Commission to become permanant accessions of the Gallery, as listed earlier in this report.

The following three paintings were returned, thus becoming the absolute property of the respective art institutions:

"The Maumee River", by Carlton T. Chapman, N. A., to the Toledo Museum of Art, Toledo, Ohio.

"Dawn", by Dwight W. Tryon, N. A., to the Carnegie Institute, Pittsburgh, Pa.

"Repose of Evening", by Ben Foster, N. A., to the University of Michigan, Ann Arbor, Mich.

SPECIAL EXHIBITIONS

Two exhibitions were held as follows:

January 12, 1937.—A special exhibition commemorating the one-hundredth anniversary of the birth of Thomas Moran, N. A. (1837–1926). This exhibition remains on view.

April 9 to 29, 1937.—Exhibition of the Second Annual Metropoliton State Art Contest, 1937, under the auspices of the department of fine arts of the District of Columbia Federation of Women's Clubs, cooperating with the following Washington art organizations: The Arts Club, the League of American Pen Women, Miniature Painters Sculptors and Gravers Society, Society of Washington Artists, Washington Landscape Club, Washington Society of Etchers, Washington Water Color Club, and a free lance group. There were 305 exhibits, prints, paintings, and sculpture by 148 artists. Cards were issued by the Gallery to an opening view.

THE NATIONAL COLLECTION OF FINE ARTS REFERENCE LIBRARY

The 388 publications accessioned during the year were obtained through purchase, transfer, gift, and exchange. One hundred and nine volumes of periodicals were sent to the bindery. The physical equipment of the library was improved by replacing the remaining wooden bookcases with steel shelves.

Miss Lucile A. Torrey was appointed librarian January 18, 1937.

SPECIAL DETAILS

The Acting Director was detailed from November 4 to 7, 1936, to visit the Syracuse Museum of Fine Arts. This made possible a careful study of the contemporary work in ceramics being done in the United States. He also visited the Walters Gallery, the Baltimore Museum of Art, and the Municipal Museum, which is devoted to the relics of Rembrandt Peale and his time.

A second detail from December 18 to 20, 1936, was granted to visit the art galleries at Chapel Hill and Charlotte, N. C.

PUBLICATIONS

Tolman, R. P. Report on the National Gallery of Art for the year ending June 30, 1936. Appendix 2, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1936, pp. 29–35.

Lodge, J. E. Report on the Freer Gallery of Art for the year ending June 30, 1936. Appendix 3, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1936, pp. 36–39, pls. 1–2.

Respectfully submitted.

R. P. Tolman, *Acting Director.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE FREER GALLERY OF ART

Sir: I have the honor to submit the seventeenth annual report on the Freer Gallery of Art for the year ending June 30, 1937:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BRONZE

37.29. Cambodian (Khmer), twelfth century. A seated Buddha. Coppery bronze with a green patina. 0.240 by 0.132 over all.

37.1. Chinese, early Chou dynasty. A ceremonial vessel of the type *yü*. White bronze with a rough green patina; small areas of unaltered metal and earthy incrustation. Decoration in low relief. Inscription in seven characters. 0.418 by 0.565 over all. (Illustrated.)

37.30. Chinese, Han dynasty. A mirror; so-called TLV type. The surface is immaculate, with a glossy black patina slightly clouded with green on the face. Diameter, 0.143.

37.15. Chinese, late Han or later. A mirror. The surface has a glossy gun-metal black patina with small areas of green *aerugo* on the back; brilliant gray clouded with black and green on the face. The decoration is in high and countersunk relief. Inscription of 56 characters. Diameter, 0.135. (Illustrated.)

37.14. Chinese, Six Dynasties or earlier. A mirror. The surface has a dark olive green patina on the back; brilliant bluish gray on the face; earthy adhesions. The principal decoration is of figures and horse-drawn chariots in moderately high relief. Diameter, 0.210.

MANUSCRIPT

37.6. Arabic, ninth-tenth century. A section of the *Qur'ān* (from Chapter II) written on 32 parchment leaves; later binding of "marbled" paper. Kufic script in dark brown ink; diacritics in red; golden *'ashiras* and verse-stops. 0.245 by 0.330, average leaf.

37.11. Arabic, ninth-tenth century. A parchment leaf from a *Qur'ān* with full page designs in gold, marking, respectively, the end of a chapter and the beginning of another. 0.122 by 0.190.

37.28. Arabic, A. D. 1283. Yāqūt al-Musta'simī, calligrapher. A bound book; later leather binding (broken): The collected verses of al-Ḥādira. *Thulth* and *naskhī* scripts in black. Dated colophon. 0.277 by 0.205, average leaf.

37.31. Arabic, fourteenth century (?). A paper leaf from a *Qur'ān*. *Naskhī* script in gold, nine lines to a page; diacritics in blue and light red. Illuminated verse-stops and two marginal *'ashiras*. 0.340 by 0.217.

37.32. Arabic, fourteenth-fifteenth century (?). A paper leaf from a *Qur‘ān.* *Naskhī* script in gold, 11 lines to a page; diacritics, verse-stops, and marginal ornaments illuminated in gold and blue. 0.335 by 0.254.

37.37. Arabic (Turkey), seventeenth century (?). A bound volume; leather binding (damaged): A collection of prayers entitled *Munājāt Qur‘ān sharīf.* Small, clear *naskhī* script in black on 53 paper leaves; headings in *thulth* script in gold and silver. Golden verse-stops; illuminated corner-pieces. 0.252 by 0.172.

37.40. Arabic (Turkey), sixteenth-seventeenth century (?). A section of the *Qur‘ān* (Chapters LXVII–LXXVII); leather binding. Alternations of *naskhī* and *thulth* scripts in black on 28 paper leaves. Titles in gold, green, or blue. 0.309 by 0.270, average leaf.

37.33–37.34. Arabic (Persia), late tenth century. Two leaves from a *Qur‘ān.* Slender Kufic script in dark brown ink on paper; diacritics in red, brown, and blue. Illuminated chapter heading (37.34 *verso*), marginal lectionary marks and verse-stops. 0.240 by 0.340. (37.33. Illustrated.)

37.41. Aramaic (Syriac), A. D. 1213–14. A bound volume (covers missing): *The New Testament. Estrangelo* script in black and red on 7 paper leaves plus 324 parchment leaves. Two colophons. 0.257 by 0.193, average leaf.

36.15. Armenian, A. D. 1669 and 1670. A volume in contemporary binding of leather overlaid with red velvet and silver appliques: The *Gospel* according to the four Evangelists. Black, red, blue, green, and golden round-hand (*bolorgir*) on 293 parchment leaves. Initials, paragraphs, title-pages, arcades, and 6 full-page miniatures, all in colors and gold. Dated colophons. 0.252 by 0.185 over all; 0.248 by 0.178, average leaf.

37.13. Armenian, fourteenth century. A leather bound volume: The *Psalter* of the orthodox Church. Black, red, blue, and golden, round-hand (*bolorgir*) on 302 parchment leaves. Miniatures (12); illuminated headings (9), initials (71), and paragraphs (70). Colophon. 0.124 by 0.086 over all; 0.115 by 0.083, average leaf.

37.19. Armenian, A. D. 1650–1. A leather bound volume with silver clasps: the orthodox *Hymnal* (*Sharaknotz*). Black, red, and golden round-hand (*bolorgir*) with musical notation on 437 parchment leaves. Miniatures (16); illuminated headpieces (9), initials (145), and paragraphs (145 plus 1). Dated head-piece and colophon. 0.121 by 0.085 over all; 0.119 by 0.078, average leaf.

37.2–37.4. Persian, sixteenth century. Three leaves from a manuscript of *Yūsuf u-Zulaikhā* by Jāmī. Each leaf is inlaid in a larger leaf of colored paper upon which border designs of animals, birds, a grapevine, and floral scrolls are executed in gold. 0.252 by 0.150, average leaf. From the same manuscript as 36.9–36.12.

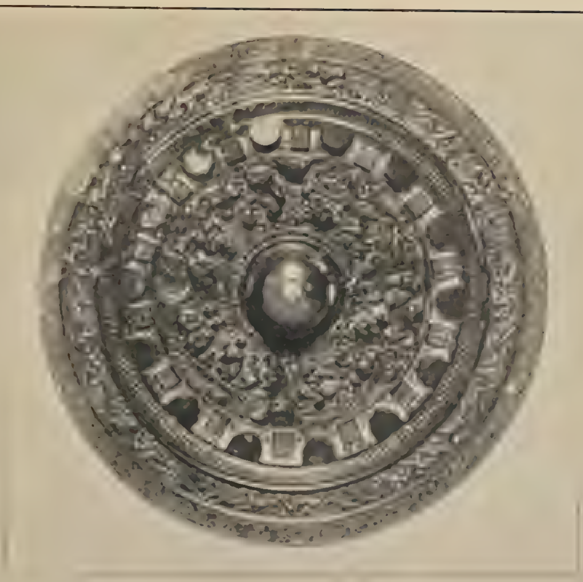
37.35. Persian, sixteenth century. A leather bound volume containing three manuscripts:

I. Shāh Mahmūd Nīshāpūrī, calligrapher. Fine *nasta‘līq* script on 28 paper leaves. Illuminated headpiece. Colophon dated in correspondence with A. D. 1523.

II. A collection of lyric poems. Minute *nasta‘līq* script on 13 paper leaves, much illuminated.

III. Salīm al-Kātib (Nīshāpūrī), Calligrapher. Bold *nasta‘līq* script in white on 5 green paper leaves. Colophon.

0.261 by 0.163, average leaf.



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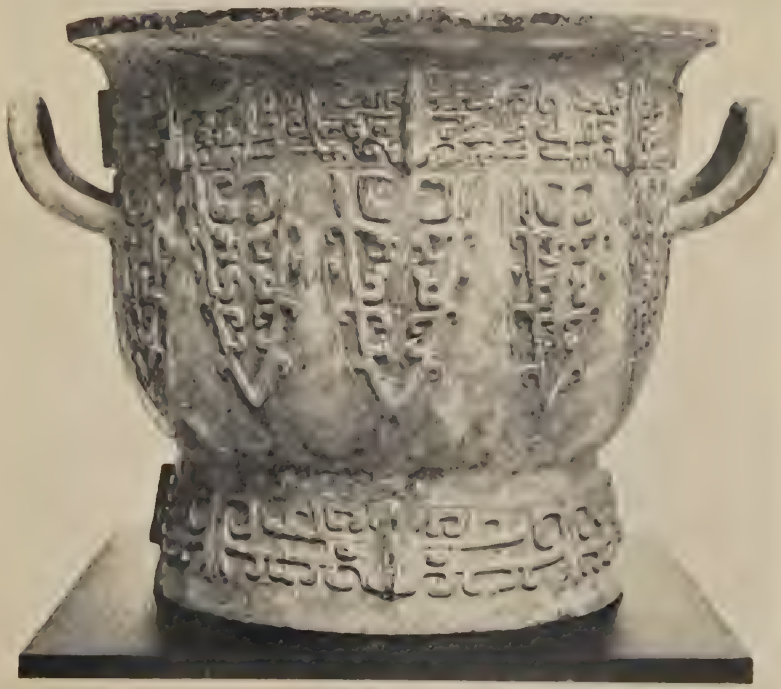
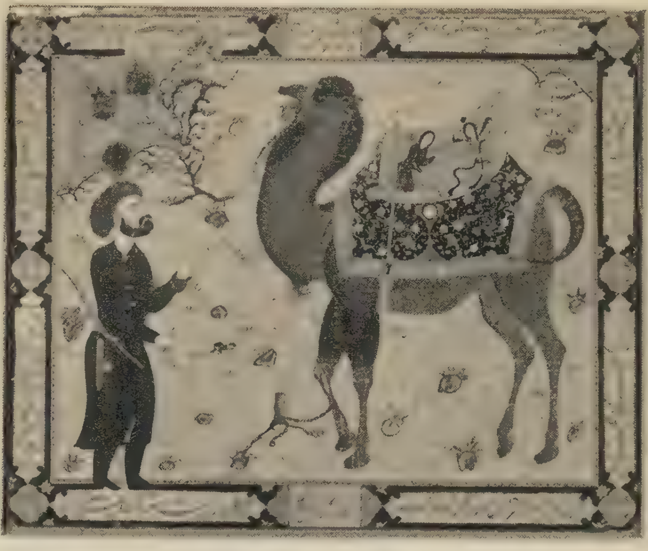


37.1

SOME RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART.



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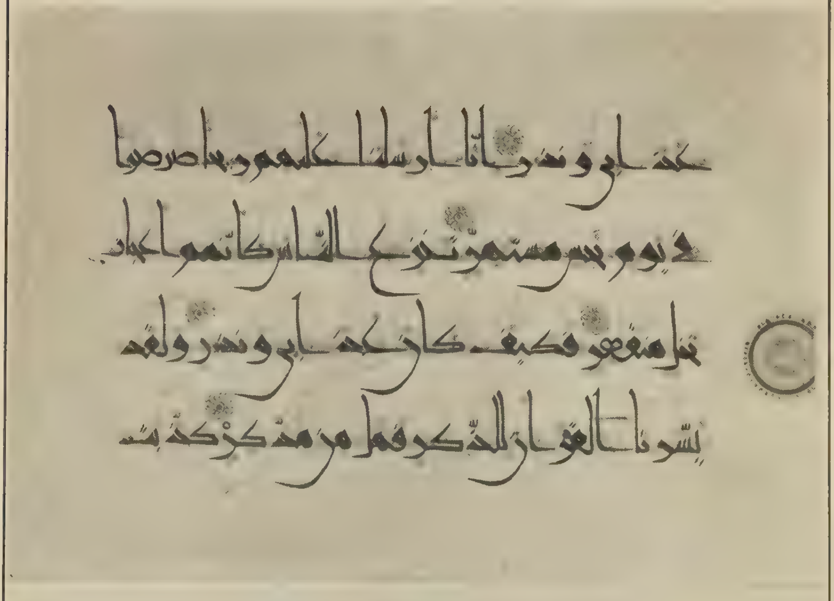


عذ ابي ونذر انا ارسلنا عليهم ريحا صرصرا
في يوم نحس مستمر تنزع الناس كانهم اعجاز
نخل منقعر فكيف كان عذ ابي ونذر ولقد
يسرنا القران للذكر فهل من مدكر كذبت ثمـ

37.33

SOME RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART.

PAINTING

37.12. Chinese Yüan period, A. D. 1352. By Wu Chên (A. D. 1280–1354). A river landscape entitled "Fishermen", after a design by Ching Hao. Ink on paper. Signature, label, poem, and dated colophon by the artist. Makimono: 0.325 by 5.622.

37.36. Indian, Rājput, Rājasthānī, sixteenth century. A musical mode (*Gujarī rāgiṇī*): a night scene with two figures—a distraught lady and her attendant. Full color on paper. Inscription. 0.196 by 0.145.

37.42. Indian, Rājput, Pahāṛī (Kāngṛā), eighteenth century. A girl with a pet antelope. Full color on paper. 0.211 by 0.149.

37.43. Indian, Rājput, Pahāṛī (Kāngṛā), late eighteenth century. A musical mode (*Pūrvā, rāgā*): Rādhā's toilette—a scene on a terrace. Colors on paper. 0.154 by 0.108.

37.44. Indian, Rājput, Pahāṛī (Kāngṛā), eighteenth–nineteenth century. A musical mode (*Pūrvā rāgā*): Rādhā's toilette—in a garden. Colors on paper. 0.169 by 0.107.

37.38–37.39. Persian, fourteenth century. Two paper leaves (trimmed): Studies of trees, from Qaswinī's Cosmography. Colors on paper. 0.090 by 0.113; 0.064 by 0.120.

37.22. Persian, Herāt school, late fifteenth century. A dromedary, hoppled, with its keeper. Full color and slight gold on paper. 0.115 by 0.145.

37.24. Persian, Herāt school, late fifteenth century. The prophets Elias and K͟haḍir at the Fountain of Life: An episode from Nizami's *Sikandarnāma*. Colors and silver (darkened) on paper. 0.157 by 0.134.

37.25. Persian, Herāt school, fifteenth century. Two demons, fettered—one with cup and wine flask, one playing a musical instrument. Tinted drawing with additions of gold on paper. 0.146 by 0.220.

37.26. Persian, Herāt school, fifteenth century. A horseman killing a lion. Colors and gold on paper. 0.140 by 0.210.

37.27. Persian, Herāt school, fifteenth century. The abduction by sea: an illustration of an episode in the poem "The Eight Paradises", included in the *K͟hamsah* of Amīr K͟husraw Dihlawī. Full color, gold and silver (darkened) on paper. 0.270 by 0.193.

37.7. Persian, Safawī period, mid-sixteenth century. By Shāh Qūlī. An angel, flying, with cup and wine flask. In ink, slight tint and gold on paper. Signature. 0.180 by 0.135.

37.8. Persian, Safawī period, sixteenth century. By Muḥammad of Herāt. Portrait of a prince wearing a mantle of gold brocade figured with pairs of captors and captives. Full color and gold on paper. Signature. 0.195 by 0.105.

37.20. Persian, Safawī period, early sixteenth century. A horse, saddled and bridled, attended by a groom. Full color and gold on paper. Inscribed with an attribution to Master Haydar 'Alī. 0.113 by 0.110.

37.21. Persian, Safawī period, sixteenth century. A camel, richly caparisoned, and his conductor. Full color and gold on paper. Signature and date written within the border: S͟hayk͟h Muḥammad, 964 (A. D. 1556–7). 0.109 by 0.132. (Illustrated.)

37.23. Persian, Safawī period, sixteenth century. Portrait of a young prince, with a parrot on his wrist. Line drawing, with additions of color, on paper. 0.147 by 0.083.

POTTERY

37.16. Chinese, Sung dynasty. *Kuan yao:* a miniature vase with tubular handles and two corresponding holes in the foot-rim. Dense, hard clay; lustrous gray glaze with large, irregular crackle. 0.102 by 0.061.

37.17. Chinese, Sung dynasty. *Ju yao:* a cup holder, with wide five-foiled flange. Hard, gray porcelaneous clay; lustrous grayish green glaze, medium crackle. 0.067 by 0.166.

37.18. Chinese, Sung dynasty. *Lung-ch‘üan yao:* a vase with long neck and two handles of fish form. Hard, dense clay; lustrous celadon glaze. 0.259 by 0.113.

37.5. Persian, Rhages (Raiy), thirteenth century. By ‘Alī bin Yūsuf. A bowl (broken and repaired). Soft, sandy, white clay; white tin enamel glaze (crazed) and a transparent wash under the foot. The decoration of people and horses is painted in polychrome enamels and leaf-gold. Kufic inscription inside; *naskhī* inscription outside; both with signature. 0.087 by 0.206.

37.9. Syrian, eleventh-twelfth century. A pitcher, thin-walled, with a low foot-rim (broken and repaired). Soft, sandy white clay; cream-white enamel glaze with traces of iridescence. Decorated with a band of Kufic lettering in low relief. 0.130 by 0.120.

37.10. Syrian, twelfth–thirteenth century. A pitcher (broken and repaired). Fairly hard, white clay; lustrous white enamel glaze of egg-shell texture. The decoration is carved in relief, with details in pierced work filled with glaze. 0.100 by 0.083.

Curatorial work has, as before, consisted largely in the study of Chinese, Tibetan, Japanese, Aramaic, Armenian, Arabic, Persian, East Indian, and Cambodian objects in the collection, of the texts and seals associated with them, and in the preparation of this material for Gallery records. In addition, 810 objects and 286 photographs of objects, Oriental for the most part, were submitted to the Curator for expert opinion as to provenance, age, quality, or other significance. Written or oral reports on these things were made to the institutions or private owners who had requested this service. Written translations of 31 inscriptions in Oriental languages were also made upon request, and 2 inscriptions—one in Chinese, the other in Egyptian hieroglyphics—were composed for the use of two Departments of the Government.

Changes in exhibition have involved a total of 92 objects, as follows:

Brass, Persian	1
Bronzes, Chinese	2
Paintings:	
American	62
Chinese	25
Textiles, Chinese	2

ATTENDANCE

The Gallery has been open to the public every day from 9 until 4:30 o'clock, with the exception of Mondays, Christmas Day, and New Year's Day.

The total attendance of visitors coming in at the main entrance was 140,881. The total attendance for week-days, exclusive of Mondays, was 94,221; Sundays, 46,660. The average week-day attendance was 365; the average Sunday attendance, 897. The highest monthly attendance was reached in April (30,837) and in August (14,084); the lowest monthly attendance in December (6,413).

There were 1,600 visitors to the main office during the year. The purposes of their visits were as follows:

For general information		354
To see objects in storage		348
Far Eastern paintings	98	
Tibetan paintings	3	
Near Eastern paintings and manuscripts	33	
East Indian paintings	5	
American paintings	83	
Whistler prints	14	
Oriental pottery, jade, bronzes, sculptures	82	
Byzantine objects	2	
American pottery	1	
Washington Manuscripts	27	
To read in the library		201
To make tracings and sketches from library books		5
To see building and installation		15
To obtain permission to photograph or sketch		7
To submit objects for examination		159
To examine or purchase photographs		370
To see members of the staff		230
To see the exhibition galleries on Mondays		40

LECTURES AND DOCENT SERVICE

Three illustrated talks were given by members of the staff before three local organizations. Upon request, 15 groups, ranging from 2 to 15 persons (total 149), were given instruction in the study rooms, and 10 groups, ranging from 10 to 50 persons (total 262), were given docent service in the exhibition galleries.

PERSONNEL

On February 15, 1937, Thomas R. Fullalove, painter, retired, after 16 years of most excellent service.

Grace T. Whitney worked intermittently at the Gallery between October 15, 1936, and June 30, 1937, on translations of Persian texts.

Respectfully submitted.

J. E. Lodge, *Curator.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 4

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

Sir: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1937, conducted in accordance with the act of Congress of March 19, 1936. The act referred to contains the following item:

> American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, $58,730.00.

SYSTEMATIC RESEARCHES

M. W. Stirling, Chief, spent the major part of the fiscal year in Washington, during which time the ethnological report on the Jivaro Indians of Ecuador was completed and submitted to the printer.

At the end of February 1937 Mr. Stirling left Washington for St. Augustine, Fla., in order to attend the conference held under the auspices of the Carnegie Institution of Washington for the purpose of outlining a program of research concerning the historical and archeological past of the city of St. Augustine and vicinity. At the conclusion of this conference he continued to Manatee, Fla., in order to examine some interesting newly discovered mounds in that vicinity. Continuing up the Gulf Coast of Florida, a visit was made to Bristol, on the Apalachicola River, where a sherd collection was made on a large mound near the river south of the town. Mr. Stirling then proceeded to Panama City, Fla., in order to photograph several private archeological collections.

From Panama City, Mr. Stirling went to Macon, Ga., for the purpose of examining the large archeological project there which was inaugurated by the Smithsonian Institution with the Society for Georgia Archeology and now being conducted under the auspices of that society by Dr. A. R. Kelly. From Macon, Mr. Stirling proceeded to Philadelphia, Pa., in order to attend the International Conference on Early Man, held under the auspices of the Philadelphia Academy of Sciences. On the conclusion of this conference Mr. Stirling returned to Washington.

Mr. Stirling was delegated to represent the Smithsonian Institution at the meeting held at Media, Pa., on May 13, 1937, in honor of the one hundredth anniversary of the birth of Daniel Brinton.

Dr. John R. Swanton, ethnologist, devoted the greater part of his time during the past fiscal year to work as chairman of the United States De Soto Expedition Commission. This involved field expeditions from November 11 to December 9, 1936, and from May 16 to June 4, 1937, except for 3 days, December 3 to 5, devoted to a meeting of the Commission at the University of Alabama, Tuscaloosa, Ala. The first field trip extended over parts of Florida, Georgia, Alabama, Mississippi, Louisiana, and Texas. The second was confined to an intensive study of that section of De Soto's route which passed through northern Mississippi. During these expeditions small collections of potsherds were made, which will be of assistance in studying the cultures of the prehistoric inhabitants of the several areas visited. As chairman of the fact-finding committee of the same Commission, Dr. Swanton prepared a report covering about 600 typewritten pages, and this was adopted by the Commission at its Tuscaloosa meeting and embodied in its report to Congress. The entire report has since been submitted, but, as publication has not yet been ordered, it is still possible to add material, and he is engaged in doing so.

During the year Dr. Swanton also made some additions to his data on the Indians of the Southeast, and he has been collecting from original sources the most important references to the Quapaw Indians.

Until the end of the fiscal year Dr. Swanton continued as a member of the executive committee of the Division of Anthropology and Psychology of the National Research Council and as vice-president of section H of the American Association for the Advancement of Science for the current calendar year.

Dr. Truman Michelson, ethnologist, renewed his researches among the Algonquian tribes of the James and Hudson Bay region under a grant-in-aid by the American Council of Learned Societies. He spent some time at Moose Factory, and a short time at Fort George, Attawapiskat, and Weenusk. Owing to the presence of some Albany Cree at Moose Factory and some Indians from Rupert's House as well as on shipboard, he was able to do personal work with them. By correspondence he obtained some additional text-material from Rupert's House; by meeting the manager of the Hudson Bay Co.'s post at the Ghost River and an Indian from Lac la Ronge he obtained data from these regions. The results of the previous expedition were checked up as much as feasible. It results that the statement made previously that east of Hannah Bay Cree leaves off and Montagnais-Naskapi begins is confirmed. Besides texts and vocabularies from the general area, a rather complete schedule of kinship terms for the Great Whale River Indians, those of Fort George, the Cree of Moose Factory, Albany, Attawapiskat, and Weenusk was obtained. Very obviously the system of consanguinity favors cross-cousin marriage; and it is to be noted that at the Great Whale River and Albany both types of this marriage occur; at Moose and Attawapiskat it is restricted to marriage with paternal aunt's daughter; at Weenusk apparently neither type obtains. It may be mentioned that by linguistic technique it is possible to show in the places named that a number of old terms have been replaced, e. g., the term for cross-nephew has been replaced by the term originally restricted to son-in-law, etc. Also the kinship systems favor exogamy, but he has not been able to find a true gens or clan organization in the whole area.

Dr. Michelson returned to Washington September 20, where he studied the material gathered on this and previous expeditions. By correspondence with Hudson Bay Co.'s officials and a missionary he obtained data on the Cree of Cumberland House, Norway House, Oxford House, Trout Lake, God's Lake (all dialects in which original *l* is replaced by *n*), Montreal Lake, Stanley, Pelecan Narrows (dialects in which original *l* is replaced by *y*). A study was made of the Montagnais of Le Jeune, over 300 years ago; the orthography plainly indicates kh, tch, and some other variations are representatives of one and the same sound, namely, the one usually transcribed by *tc*. This study enabled him also to make at least one correction to the Handbook of American Indians, and prove one supposed Algonkin tribe actually was Montagnais-Naskapi. From correspondence it would appear that the dialect spoken at Island Lake is a mixture of Cree, Ojibwa, and possibly Algonkin proper. This indicates that in a number of places there is such a mixture, but apparently not on the same scale. A map showing the distribution and interrelations of the Cree and Montagnais-Naskapi dialects has been made. Technical papers have appeared in professional journals, and others have been prepared and are awaiting publication. The Bureau published Fox Miscellany (Bulletin 114), the proof-sheets of which were corrected during the fiscal year.

At the beginning of the fiscal year, Dr. John P. Harrington, ethnologist, prepared a report on the Use of Ferns in the Basketry of the Indians of Northwestern California, centering on the use of fern species among the Karuk tribe. The baskets of this section are really built of lumber, that is, of the shredded roots of the Oregon pine. But the two materials which make the baskets beautiful are the glossy black of maidenhair fern stems and the handsome red of Woodwardia fern filaments, dyed with alder bark.

Dr. Harrington next prepared a paper on Kiowa Memories of the Black Hills and of the Devil's Tower. The Kiowa Indians, 600 miles to the south, still have memories of the Black Hills country of South Dakota, which they occupied some 150 years ago. They also retain knowledge of myths regarding the remarkable basalt column near Sundance, Wyo., on the northwestern slope of the Black Hills, known as the Devil's Tower, but to the Kiowa as the Rock Standing Like a Tree. An elaborate paper was finished on the subject, going into the geology, history, and mythology of the Devil's Tower.

Dr. Harrington next finished a report on The Northern Provenience of the Navaho and Apache, tracing related languages in detail to Alaska, northwestern Canada, and the Pacific Coast of the United States, and telling in detail how the relationship of Navaho and Apache to the Indians of the far northwest was discovered by W. W. Turner, librarian in the Patent Office, Washington, D. C., in 1852. This voluminous report resulted in the discovery by Dr. Harrington of a curious distribution of these languages, the map of which takes the form of a wishbone. Their nucleus is in the far Northwest, one prong extending down the Pacific Coast and terminating a little north of San Francisco Bay, another eastern prong extending down through the Rocky Mountain region and culminating in the Navaho and Apache of the Southwest. An exhaustive study was made of the earliest documents and maps on the subject, in the compilation of which Dr. Harrington was assisted by the Geographic Board of Canada.

A report was completed on the Siberian Origin of the American Indian, presenting the background, the earliest historic writings on the subject, the Eskimo problem, the problem of the means of crossing (whether by boat, over ice, or by means of former land bridge), the distribution of tribes and density of population as bearing out the theory, and general aspects. In this study he was assisted by many other students, including native interpreters of the Bering Strait region. This report suggests that America was first discovered as a result of over-population which developed in the east of Asia and forced Paleo-Siberian peoples to enter the Chukchi Peninsula. From this point they sighted and spilled over into America, using the Diomede Islands as resting places on their transit, if this were during the period of the existence of the Bering Strait, and followed the food supply down what is now the Alaskan coast, without realizing that they had discovered anything more than an outlying island.

A paper was prepared on the Life of Jeronimo, Apache Indian Chief, and the Indian leader whose expeditions probably cost the United States Government more money and trouble than did those of any other chieftain. The life and times of Jeronimo were minutely searched, and data were compiled in chronological order. The material of this paper is especially interesting to the American public as it deals with a period already dimming in the memories of living men. The name, Alope, of the first wife of Jeronimo, was discovered to be merely a corruption of the Mexican Spanish name Guadalupe.

Studies on linguistic relationship in the Southwest and California were continued. These studies have resulted in the discovery that Tano-Kiowan and Aztecan are genetically related, and to this larger group Dr. Harrington gave the name Patlan. The discovery was also made that Hopi is a Southern California Shoshonean dialect, showing developments in common with the Southern California Shoshonean dialects, and constituting with them a dialectic group of the Aztecan family in contradistinction to any other group. This unity of Hopi with Southern California Shoshonean was first noticed many years ago, the word for wood-rat (e. g., Hopi *qáala*, wood-rat, Southern California Shoshonean *qáala*, wood-rat) leading immediately to the discovery. It was also noticed by Dr. J. R. Swanton and Dr. Harrington that Tano-Kiowan and Shoshonean have genetic relationship with the languages of the Southeastern United States (Muskhogean, Chitimacha, Atakapa, Tonkawa, Timucua), Tano-Kiowan, for instance, and all the Southeastern languages above-mentioned showing the characteristic prefix *na-*, something, used in deriving nouns from verbs (e. g., Tanoan *tha*, to dwell; *natha*, house).

At the beginning of the fiscal year Dr. Frank H. H. Roberts, Jr., archeologist, was engaged in excavating at the Lindenmeier site in northern Colorado. At this place remains attributable to the material culture of Folsom man, one of the earliest known inhabitants of the New World, are found. The 1936 investigations constituted the third season's work there, and valuable new information was obtained on this important phase in the study of the history of the American Indian. Digging was carried on at three different portions of the site, and considerable new bone material and several new types of implements came from the excavations. Most of the bones were from the large extinct species of bison (*Bison taylori*) which the people hunted, but in addition a number of bones from the American camel, probably *Camelops*, were obtained in direct association with the bison bones and with stone implements. This adds one more extinct species of animal to the list of those found with Folsom artifacts. One of the significant facts established by the work is that the site was occupied before and during a period characterized by the formation of a thick, black soil layer produced by heavy vegetation that thrived when conditions were more favorable than those of recent times. That the people were there before the inception of this era of abundant growth points to an even greater antiquity than that suggested by the presence of implements and bones in the bottom of the soil level. The work was brought to a close September 5, 1936.

In the latter part of August Dr. Roberts also investigated a site near Kersey, Colo., where Folsom type objects were found by F. W. Powars and his son Wayne, residents of Greeley. This location is on a low terrace of the rolling terrain lying along the south side of the South Platte River valley. Present evidence indicates that it was a camp, but one occupied for a relatively short period of time. Specimens obtained there represent a typical Folsom complex. They are so similar to those from the Lindenmeier site that it is difficult to distinguish between specimens from the two sites. Bones are scarce, and those recovered are so fragmentary that they are valueless for determining the species of the animals represented.

After the completion of the Lindenmeier and Powars site investigations Dr. Roberts proceeded to Sterling, Colo., where he visited and inspected a number of sites in that vicinity. All proved to be of more recent origin than the Folsom type material. From Sterling Dr. Roberts returned to Washington. The autumn months were spent in the office working over the material obtained during the summer's investigations.

February 24 Dr. Roberts sailed for Cairo, Egypt, where he served as one of two American experts at the International Conference of Archeologists held March 9 to 17, under the auspices of the Committee for Intellectual Cooperation of the League of Nations. As his part of the agenda for the sessions, Dr. Roberts presented a paper on the subject "The Material Organization of an Archeological Mission." This included a discussion of the choice of personnel for a field staff, the securing of equipment, the establishment of field headquarters, and the general administration of such a project. At the close of the conference he visited a number of sites in Egypt and had an opportunity to study methods of excavation and general archeological procedure as practiced in the Egyptian area. From Egypt he went to Greece, Italy, France, and England and studied collections in the museums at Athens, Naples, Rome, Paris, and London. He returned to Washington April 24.

On May 21 Dr. Roberts left Washington for Kingman, Ariz., where he and C. W. Gilmore, curator of vertebrate paleontology, United States National Museum, investigated a find of mastodon bones and man-made objects. The deposit is located near a large spring 24 miles west of Kingman. A week's study and excavation demonstrated that the material was a secondary deposit, washed in from surrounding slopes, and of no importance from the standpoint of the association of man and extinct mammals. Dr. Roberts left Kingman on June 2 for Denver, Colo., and Fort Collins. On June 12 he resumed excavations at the Lindenmeier site. By the end of the fiscal year an area covering 375 square feet had been uncovered. Numerous implements and considerable additional information were obtained from this work. These data serve to round out more fully the story of the customs and habits of Folsom man.

During the winter months Dr. Roberts also prepared several manuscripts on the subject of the work at the Lindenmeier site and on Southwestern archeology in general.

Upon his return from Spanish Honduras early in the fiscal year, Dr. W. D. Strong, anthropologist, spent his entire time in working over the archeological collections from the Ulua River. With the assistance of Alfred Kidder II, and Drexel A. Paul, Jr., Dr. Strong completed the report on this work which is to be published in the Smithsonian Miscellaneous Collections under the title "Preliminary Report on the Smithsonian Institution-Harvard University Archeological Expedition to Northwestern Honduras, 1936."

From July 1 until late October 1936, Dr. Julian H. Steward, associate anthropologist, continued his work of the previous year among Shoshonean tribes in the Great Basin and Plateau areas. He had two objectives: First, to study the ecological basis of the social and political organization of the bands of horse Shoshoni in Utah and Idaho to supplement his previous study of the foot Shoshoni of Nevada; second, to continue his ethnographic survey by means of an element list. An element list and satisfactory ecological material were procured from the following: Bannock, Fort Hall Shoshoni, Lemhi Shoshoni, and Grouse Creek (northwestern Utah) Shoshoni at Fort Hall, Idaho; Promontory Point (Great Salt Lake) Shoshoni at Washakie, Utah; Pahvant Ute (now almost extinct) at Kanosh, Utah; Gosiute (determined to be actually Shoshoni) at Skull Valley and at Deep Creek, Utah. Before returning to Washington, Dr. Steward drove to Fallon, Nev., to examine guano caves said to hold promise, but found little of interest. He returned by way of southern Nevada and southern Utah, making brief visits to several Southern Paiute reservations. The remainder of the year was devoted to preparation of research material for publication, and eight manuscripts have been completed.

The beginning of the fiscal year found J. N. B. Hewitt, ethnologist, on the Tuscarora Reservation near Lewiston, N. Y., where he went to continue his researches on the League of the Five Iroquois Tribes. From Lewiston Mr. Hewitt proceeded to the Grand River Grant to the Six Nations in Ontario. Here he had the good fortune to obtain a complete Mohawk text embodying the so-called Handsome Lake religious teaching, this document consisting of more than 5,700 Mohawk terms. Considerable additional information was obtained concerning the interesting dual nature of the tribal organization. On his return to Washington Mr. Hewitt completed the translation of the Mohawk text giving details of the birth and early childhood of Deganawida, also another Mohawk text giving an account of the dancing lads who finally became the Pleiades.

During the month of June 1937, Mr. Hewitt again left Washington for Brantford, Canada, in order to check over in the field his two large manuscripts in Onondaga text, one being the Iroquois New Year Ceremony and the other consisting of the four Thanksgiving Festivals. The end of the fiscal year found Mr. Hewitt still in the field engaged in this task.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the Bureau was continued through the year by Stanley Searles, editor.

Bulletin 114, Fox Miscellany, by Truman Michelson, was issued during the year.

Bulletin 115, Journal of Rudolph Friederich Kurz, edited by J. N. B. Hewitt, was released for printing.

Bulletin 116, Ancient Caves of the Great Salt Lake Region, by Julian H. Steward, was released for printing.

An index of Schoolcraft's Indian Tribes, in six volumes, has been further advanced toward completion.

Work has been done on other manuscripts in the custody of the editor.

Publications distributed totaled 14,708.

LIBRARY

Miss Miriam B. Ketchum continued in charge throughout the year as librarian.

Accessions during the fiscal year numbered 580 volumes, bringing the total number of volumes in the library to 31,115; there are also about 20,000 pamphlets and about 2,000 volumes of unbound periodicals and society transactions.

The number of volumes prepared and sent to bindery was 1,330.

Library of Congress cards have been obtained for practically all of the new books received during the year and for some of the older material. All new material is being classed in the Library of Congress scheme of classification and separately shelved. A partial depository set of Library of Congress catalog cards has been established and will shortly be installed in working order.

The work of refiling the catalog continues. Thirteen drawers are now finished.

A great many missing numbers have been requested and nearly all of these have been supplied, amounting in some cases to several volumes of a set. Of the exchange sets, 8 old sets which had been allowed to lapse have been reestablished, and 11 new sets have been established.

ILLUSTRATIONS

Following is a summary of the work accomplished by E. G. Cassedy, illustrator:

Line drawings	266
Graphs	13
Plates lettered or numbered	199
Plates assembled	64
Plates sized for engraver	129
Airbrush jobs	6
Photos retouched	51
Topographic maps	3
Maps	3
Mechanical drawings	3
Lettering jobs	3
Engrossings	2
Water color paintings	1
Total	743

COLLECTIONS

Accession number

140,528. Skeletal material from two sites on Canaveral Peninsula, Brevard County, Fla., collected by the Bureau in cooperation with the Federal Civil Works Administration during the winter of 1933–34. (250 specimens.)

142,561. Archeological specimens and human and animal bones collected during mound excavations in Florida during the winter of 1933–34 in cooperation with the Federal C. W. A.

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Personnel.—Miss Helen Heitkemper, junior stenographer, resigned March 16, 1937. Miss Ethelwyn E. Carter was appointed May 1, 1937, to fill the vacancy.

Respectfully submitted.

M. W. Stirling, *Chief.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the activities of the International Exchange Service during the fiscal year ended June 30, 1937:

For that year the congressional appropriation was $44,260. Some years ago, in order to supplement the amounts granted by Congress, which have never been sufficient to meet the entire expenses of the Exchange Service, the Board of Regents of the Institution gave authority to charge governmental establishments 5 cents a pound for forwarding their publications abroad through exchange channels. The collections from that source during the year were $3,871.49, making the total resources available $48,131.49.

The number of packages handled during 1937 was 657,346, an increase of 60,395. The weight was 651,461 pounds, an increase of 32,672 pounds.

The following table gives the number and weight of packages sent and received through the Exchange Service separated into three classes: Parliamentary documents, departmental documents, and scientific and literary publications.

	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad	303, 054		114, 439	
Publications received in return for parliamentary documents		9, 633		29, 316
United States departmental documents sent abroad	122, 261		123, 286	
Publications received in return for departmental documents		9, 010		32, 624
Scientific and literary publications sent abroad	160, 631		239, 402	
Scientific and literary publications received from abroad for distribution in the United States		52, 757		112, 394
Total	585, 946	71, 400	477, 127	174, 334
Grand total	657,346		651,461	

The number of boxes shipped abroad was 2,620, an increase of 145 over the preceding year. Of these boxes, 540 were for depositories of full sets of United States governmental documents, and the remainder (2,080) were for distribution to miscellaneous establishments and individuals. In addition to the packages forwarded in these boxes there were transmitted by mail 87,296, an increase of 16,397 over last year.

BRUSSELS EXCHANGE CONVENTIONS

In 1886, some years after the organization of the Smithsonian system of exchanges, there were concluded at Brussels between the United States and a number of other countries two exchange conventions. The first, Convention A (Stat., XXV, 1465), provided for the international exchange of official documents and scientific and literary publications; and the second, Convention B (Stat., XXV, 1469), provided for the immediate exchange of the official journal. The Smithsonian Institution was charged by the Congress with the duty of carrying out the provisions of those conventions on the part of the United States (Stat., XIV, 573—Congressional Resolution approved Mar. 2, 1867, setting aside 50 copies of all governmental documents for exchange purposes; Stat., XXXI, 1464—Congressional Resolution approved Mar. 2, 1901, increasing the number of documents for exchange to not exceeding 100 copies; Stat., XLIII, 1106—Printing Act approved Mar. 2, 1901, further increasing the number to 125 copies; and Stat., XXXV, 1169—Congressional Resolution approved Mar. 4, 1909, setting aside copies of the Congressional Record for exchange with foreign parliamentary bodies).

Eight countries signed the first convention, namely the United States, Belgium, Brazil, Italy, Portugal, Serbia (now Yugoslavia), Spain, and Switzerland. The second convention was signed by all of those countries except Switzerland. Since the ratification of the Brussels Conventions the following countries have signified their adherence thereto in the order in which they are listed:

1. Uruguay—both conventions, 1889.
2. Argentine Republic—convention A, 1889.
3. Paraguay—convention A, 1889.
4. Czechoslovakia—both conventions, 1919.
5. Poland—convention A, 1920; convention B, 1921.
6. Rumania—both conventions, 1923.
7. Hungary—both conventions, 1923.
8. Dominican Republic—both conventions, 1923.
9. Latvia—both conventions, 1924.
10. Free City of Danzig—both conventions, 1924.
11. China—both conventions, 1925.
12. Egypt—convention A, 1925.

Although not all countries joined the exchange conventions, most of those not listed above have entered into exchange relations with the United States and have established official bureaus to conduct the work.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

There are forwarded to foreign depositories 111 sets of United States official publications, 61 of these being full sets and 50 partial sets. The depository of the full set forwarded to Peru has been changed from the Biblioteca Nacional to the Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.

DEPOSITORIES OF FULL SETS

ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.
  BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata, La Plata. (Depository of the Province of Buenos Aires.)
AUSTRALIA: Library of the Commonwealth Parliament, Canberra.
  NEW SOUTH WALES: Public Library of New South Wales, Sydney.
  QUEENSLAND: Parliamentary Library, Brisbane.
  SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
  TASMANIA: Parliamentary Library, Hobart.
  VICTORIA: Public Library of Victoria, Melbourne.
  WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
AUSTRIA: National Bibliothek, Wien I.
BELGIUM: Bibliothèque Royale, Bruxelles.
BRAZIL: Bibliotheca Nacional, Rio de Janeiro.
CANADA: Library of Parliament, Ottawa.
  MANITOBA: Provincial Library, Winnipeg.
  ONTARIO: Legislative Library, Toronto.
  QUEBEC: Library of the Legislature of the Province of Quebec.
CHILE: Biblioteca del Congreso, Santiago.
CHINA: National Central Library, Nanking.
COLOMBIA: Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Secretaría de Estado (Asuntos Generales y Canje Internacional), Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Kongelige Bibliotheket, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn.
FRANCE: Bibliothèque Nationale, Paris.
GERMANY: Reichstauschstelle im Reichsministerium des Innern, Berlin C 2.
  BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the State of Baden.)
  BAVARIA: Bayerische Staatsbibliothek, München.
  PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
  SAXONY: Sächsische Landesbibliothek, Dresden—N. 6.
  WURTEMBURG: Landesbibliothek, Stuttgart.
GREAT BRITAIN:
  ENGLAND: British Museum, London.
  GLASGOW: City Librarian, Mitchell Library, Glasgow.
  LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
HUNGARY: A Magyar országgyülés könyvtará, Budapest.
INDIA: Imperial Library, Calcutta.
IRISH FREE STATE: National Library of Ireland, Dublin.
ITALY: Ministero dell'Educazione Nazionale, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LATVIA: Bibliothèque d'État, Riga.
LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.

Mexico: Biblioteca Nacional, Mexico, D. F.
Netherlands: Royal Library, The Hague.
New Zealand: General Assembly Library, Wellington.
Northern Ireland: H. M. Stationery Office, Belfast.
Norway: Universitets-Bibliothek, Oslo. (Depository of the Government of Norway.)
Peru: Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.
Poland: Bibliothèque Nationale, Warsaw.
Portugal: Bibliotheca Nacional, Lisbon.
Rumania: Academia Română, Bucharest.
Spain: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, Madrid.
Sweden: Kungliga Biblioteket, Stockholm.
Switzerland: Bibliothèque Centrale Fédérale, Berne.
Turkey: Ministère de l'Instruction Publique, Ankara.
Union of South Africa: State Library, Pretoria, Transvaal.
Union of Soviet Socialist Republics: State Central Book Chamber, Moscow 4.
  Ukraine: All-Ukrainian Association for Cultural Relations with Foreign Countries, Kiev.
Uruguay: Oficina de Canje Internacional de Publicaciones, Montevideo.
Venezuela: Biblioteca Nacional, Caracas.
Yugoslavia: Ministère de l'Éducation, Belgrade.

DEPOSITORIES OF PARTIAL SETS

Afghanistan: Ministry of Foreign Affairs, Publications Department, Kabul.
Austria: Vienna: Magistrat der Stadt Wien, Abteilung 51-Statistik.
Bolivia: Biblioteca del H. Congreso Nacional, La Paz.
Brazil:
  Minas Geraes: Directoria Geral de Estatistica em Minas, Bello Horizonte.
  Rio de Janeiro: Bibliotheca da Assemblea Legislativa do Estado, Nictheroy.
British Guiana: Government Secretary's Office, Georgetown, Demerara.
Bulgaria: Ministère des Affaires Étrangères, Sofia.
Canada:
  Alberta: Provincial Library, Edmonton.
  British Columbia: Provincial Library, Victoria.
  New Brunswick: Legislative Library, Fredericton.
  Nova Scotia: Provincial Secretary of Nova Scotia, Halifax.
  Prince Edward Island: Legislative Library, Charlottetown.
  Saskatchewan: Government Library, Regina.
Ceylon: Chief Secretary's Office (Record Department of the Library), Colombo.
China: National Library, Peiping.
Danzig: Stadtbibliothek, Danzig.
Dominican Republic: Biblioteca del Senado, Ciudad Trujillo.
Ecuador: Biblioteca Nacional, Quito.
Finland: Parliamentary Library, Helsingfors.
Germany:
  Bremen: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
  Hamburg: Staats-und Universitäts-Bibliothek.
  Hesse: Universitäts-Bibliothek, Giessen.
  Lübeck: President of the Senate.
  Thuringia: Rothenberg-Bibliothek, Landesuniversität, Jena.
Greece: Library of Parliament, Athens.

GUATEMALA: Biblioteca Nacional, Guatemala.
HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.
HONDURAS: Biblioteca y Archivo Nacionales, Tegucigalpa.
ICELAND: National Library, Reykjavik.
INDIA:
    ASSAM: General and Judicial Department, Shillong.
    BENGAL: Secretary, Bengal Legislative Council Department, Council House, Calcutta.
    BIHAR and ORISSA: Revenue Department, Patna.
    BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.
    BURMA: Secretary to the Government of Burma, Education Department, Rangoon.
    CENTRAL PROVINCES: General Administration Department, Nagpur.
    MADRAS: Chief Secretary to the Government of Madras, Public Department, Madras.
    PUNJAB: Chief Secretary to the Government of the Punjab, Lahore.
    UNITED PROVINCES OF AGRA AND OUDH: University of Allahabad, Allahabad.
JAMAICA: Colonial Secretary, Kingston.
LIBERIA: Department of State, Monrovia.
LITHUANIA: Ministère des Affaires Étrangères, Kaunas (Kovno).
MALTA: Minister for the Treasury, Valletta.
NEWFOUNDLAND: Department of Home Affairs, St. John's.
NICARAGUA: Superintendente de Archivos Nacionales, Managua.
PANAMA: Secretaría de Relaciones Exteriores, Panama.
PARAGUAY: Secretario de la Presidencia de la República, Asunción.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.
STRAITS SETTLEMENTS: Colonial Secretary, Singapore.
VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

The forwarding of copies of the Congressional Record and the Federal Register to the Bibliothek des Preussischen Landtags, Berlin, has been discontinued as the Landtag has been abolished. The following have been added to the list of those receiving the Congressional Record and the Federal Register: Staatskanzlei des Kantons Berne, Staatskanzlei des Kantons St. Gallen, Staatskanzlei des Kantons Schaffhausen, and Staatskanzlei des Kantons Zürich. The total number of copies of these documents now forwarded abroad is 105. A complete list of the depositories is given below:

DEPOSITORIES OF CONGRESSIONAL RECORD

ALBANIA: Ministrija Mibretnore e Punëvetë Jashtme, Tirana.
ARGENTINA:
    Biblioteca del Congreso Nacional, Buenos Aires.
    Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.
AUSTRALIA:
    Library of the Commonwealth Parliament, Canberra.
    NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.
    QUEENSLAND: Chief Secretary's Office, Brisbane.
    WESTERN AUSTRALIA: Library of Parliament of Western Australia, Perth.

AUSTRIA: Bibliothek des Hauses der Bundesgesetzgebung, Wien I.
BELGIUM: Bibliothèque de la chambre des Représentants, Bruxelles.
BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.
BRAZIL:
  Bibliotheca do Congresso Nacional, Rio de Janeiro.
  AMAZONAS: Archivo, Bibliotheca e Imprensa Publica, Manáos.
  BAHIA: Governador do Estado da Bahia, São Salvador.
  ESPIRITO SANTO: Presidencia do Estado do Espirito Santo, Victoria.
  RIO GRANDE DO SUL: "A Federação", Porto Alegre.
  SERGIPE: Bibliotheca Publica do Estado de Sergipe, Aracajú.
  SÃO PAULO: Diario Official do Estado de São Paulo, São Paulo.
BRITISH HONDURAS: Colonial Secretary, Belize.
CANADA:
  Library of Parliament, Ottawa.
  Clerk of the Senate, Houses of Parliament, Ottawa.
CHINA: National Central Library, Nanking.
CUBA: Biblioteca del Capitolio, Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DANZIG: Stadtbibliothek, Danzig.
DENMARK: Rigsdagens Bureau, Copenhagen.
DOMINICAN REPUBLIC: Biblioteca del Senado, Ciudad Trujillo.
DUTCH EAST INDIES: Volksraad von Nederlandsch-Indië, Batavia, Java.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn.
FRANCE:
  Chambre des Députés, Service de l'Information Parlementaire Étrangère, Paris.
  Bibliothèque du Sénat, au Palais du Luxembourg, Paris.
  Bibliothèque, Direction des Accords commerciaux, Ministère du Commerce, Paris.
GERMANY:
  Deutsche Reichstags-Bibliothek, Berlin, N. W. 7.
  Reichsfinanzministerium, Berlin, W. 8.
  ANHALT: Anhaltische Landesbücherei, Dessau.
  BRAUNSCHWEIG: Bibliothek des Braunschweigischen Staatsministeriums, Braunschweig.
  MECKLENBURG: Staatsministerium, Schwerin.
  OLDENBURG: Oldenburgisches Staatsministerium, Oldenburg i. O.
  SCHAUMBURG-LIPPE: Schaumburg-Lippische Landesregierung, Bücheburg.
GIBRALTAR: Gibraltar Garrison Library Committee, Gibraltar.
GREAT BRITAIN: Library of the Foreign Office, London.
GREECE: Library of Parliament, Athens.
GUATEMALA: Biblioteca de la Asamblea Legislativa, Guatemala.
HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.
HUNGARY: A Magyar országgyülés könyvtará, Budapest.
INDIA: Legislative Department, Simla.
IRAN: Library of the Iranian Parliament, Téhéran.
IRAQ: Chamber of Deputies, Baghdad.
IRISH FREE STATE: Dail Eireann, Dublin.
ITALY:
  Biblioteca della Camera dei Deputati, Rome.
  Biblioteca del Senato del Regno, Rome.
  Ufficio degli Studi Legislativi, Senato del Regno, Rome.
LATVIA: Valsts Biblioteka, Riga.

LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.
LIBERIA: Department of State, Monrovia.
MEXICO: Secretaría de la Cámara de Diputados, Mexico, D. F.
    AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.
    CAMPECHE: Gobernador del Estado de Campeche, Campeche.
    CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.
    CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.
    COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.
    COLIMA: Gobernador del Estado de Colima, Colima.
    DURANGO: Gobernador Constitucional del Estado de Durango, Durango.
    GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.
    GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.
    JALISCO: Biblioteca del Estado, Guadalajara.
    LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali, B. C., Mexico.
    MEXICO: Gaceta del Gobierno, Toluca, Mexico.
    MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.
    MORELOS: Palacio de Gobierno, Cuernavaca.
    NAYARIT: Gobernador de Nayarit, Tepic.
    NUEVO LEON: Biblioteca del Estado, Monterey.
    OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.
    PUEBLA: Secretaría General de Gobierno, Puebla.
    QUERETARO: Secretaría General de Gobierno, Sección de Archivo, Queretaro.
    SAN LUIS POTOSI: Congreso del Estado, San Luis Potosi.
    SINALOA: Gobernador del Estado de Sinaloa, Culiacan.
    SONORA: Gobernador del Estado de Sonora, Hermosillo.
    TABASCO: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.
    TAMAULIPAS: Secretaría General de Gobierno, Victoria.
    TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.
    VERA CRUZ: Gobernador del Estado de Vera Cruz, Departamento de Gobernación y Justicia, Jalapa.
    YUCATÁN: Gobernador del Estado de Yucatán, Mérida, Yucatán.
NEW ZEALAND: General Assembly Library, Wellington.
NORWAY: Storthingets, Bibliothek, Oslo.
PERU: Cámara de Diputados, Lima.
POLAND: Bibljoteka Narodowa, Warsaw.
PORTUGAL: Secretario da Assemblea Nacional, Lisboa.
RUMANIA:
    Bibliothèque de la Chambre des Députés, Bucharest.
    Ministère des Affaires Étrangères, Bucharest.
SPAIN:
    Biblioteca del Congreso Nacional, Madrid.
    Catalunya: Biblioteca del Parlament de Catalunya, Barcelona.
SWITZERLAND: Bibliothèque de l'Assemblée Fédérale Suisse, Berne.
    Berne: Staatskanzlei des Kantons Berne.
    St. Gallen: Staatskanzlei des Kantons St. Gallen.
    Schaffhausen: Staatskanzlei des Kantons Schaffhausen.
    Zürich: Staatskanzlei des Kantons Zürich.
SYRIA:
    Ministère des Finances de la République Libanaise, Service du Matériel, Beirut.
    Governor of the State of Alaouites, Lattaquié.

Turkey: Turkish Grand National Assembly, Ankara.
Union of South Africa:
  Library of Parliament, Cape Town, Cape of Good Hope.
  State Library, Pretoria, Transvaal.
Uruguay: Diario Oficial, Calle Florida 1178, Montevideo.
Venezuela: Biblioteca del Congreso, Caracas.
Vatican City: Biblioteca Apostolica Vaticana, Vatican City, Italy.

FOREIGN EXCHANGE AGENCIES

The work of the Peruvian Exchange Agency has been transferred from the Biblioteca Nacional to the Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.

LIST OF EXCHANGE AGENCIES

Algeria, via France.
Angola, via Portugal.
Argentina: Comisión Protectora de Bibliotecas Populares, Canje Internacional, Calle Callao 1540, Buenos Aires.
Austria: Internationale Austauschstelle, National-Bibliothek, Wien, I.
Azores, via Portugal.
Belgium: Service Belge des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.
Bolivia: Oficina Nacional de Estadística, La Paz.
Brazil: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.
British Guiana: Royal Agricultural and Commercial Society, Georgetown.
British Honduras: Colonial Secretary, Belize.
Bulgaria: Institutions Scientifiques de S. M. de Roi de Bulgarie, Sofia.
Canada: Sent by mail.
Canary Islands, via Spain.
Chile: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.
China: Bureau of International Exchange, National Central Library, Nanking.
Colombia: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.
Costa Rica: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
Cuba: Sent by mail.
Czechoslovakia: Service Tchécoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblèe Nationale, Prague 1–79.
Danzig: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.
Denmark: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Copenhagen V.
Dutch Guiana: Surinaamsche Koloniale Bibliotheek, Paramaribo.
Ecuador: Ministerio de Relaciones Exteriores, Quito.
Egypt: Government Press, Publications Office, Bulaq, Cairo.
Estonia: Riigiraamatukogu (State Library), Tallinn.
Finland: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsingfors.
France: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.

GREAT BRITAIN AND IRELAND: Wheldon & Wesley, 2–4 Earnshaw St., New Oxford St., London, W. C. 2.

GREECE: Bibliothèque Nationale, Athens.

GREENLAND, via Denmark.

GUATEMALA: Instituto Nacional de Varones, Guatemala.

HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.

HONDURAS: Biblioteca Nacional, Tegucigalpa.

HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.

ICELAND, via Denmark.

INDIA: Superintendent of Government Printing and Stationery, Bombay.

ITALY: R. Ufficio degli Scambi Internazionali, Ministero dell' Educazione Nazionale, Rome.

JAMAICA: Institute of Jamaica, Kingston.

JAPAN: Imperial Library of Japan, Uyeno Park, Tokyo.

JAVA, via Netherlands.

LATVIA: Service des Échanges Internationaux, Bibliothèque d'Etat de Lettonie, Riga.

LIBERIA: Bureau of Exchanges, Department of State, Monrovia.

LITHUANIA: Sent by mail.

LOURENÇO MARQUEZ, via Portugal.

LUXEMBOURG, via Belgium.

MADAGASCAR, via France.

MADEIRA, via Portugal.

MEXICO: Sent by mail.

MOZAMBIQUE, via Portugal.

NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

NEW ZEALAND: General Assembly Library, Wellington.

NICARAGUA: Ministerio de Relaciones Exteriores, Managua.

NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.

PALESTINE: Hebrew University Library, Jerusalem.

PANAMA: Sent by mail.

PARAGUAY: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Asunción.

PERU: Sección de Propaganda y Publicationes, Ministerio de Relaciones Exteriores, Lima.

POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.

PORTUGAL: Secção de Trocas Internacionaes, Bibliotheca Nacional, Lisboa.

QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.

RUMANIA: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.

SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.

SIAM: Department of Foreign Affairs, Bangkok.

SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.

SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, bajo derecha, Madrid.

Sumatra, via Netherlands.

Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.

Switzerland: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.

Syria: American University of Beirut.

Tasmania: Secretary to the Premier, Hobart.

Trinidad: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.

Tunis: via France.

Turkey: Robert College, Istanbul.

Union of South Africa: Government Printing and Stationery Office, Cape Town, Cape of Good Hope.

Union of Soviet Socialist Republics: Library of the Academy of Sciences of the U. S. S. R., Exchange Service, Leningrad, V. O.

Uruguay: Oficina de Canje Internacional de Publicaciones, Ministerio de Relaciones Exteriores, Montevideo.

Venezuela: Biblioteca Nacional, Caracas.

Victoria: Public Library of Victoria, Melbourne.

Western Australia: Public Library of Western Australia, Perth.

Yugoslavia: Section des Échanges Internationaux, Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

C. W. Shoemaker, *Chief Clerk.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE NATIONAL ZOOLOGICAL PARK

Sir: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ended June 30, 1937:

The regular appropriation made by Congress for the maintenance of the Park was $225,000, all of which was expended.

IMPROVEMENTS

The fiscal year 1937 was probably the most outstanding in the history of the Zoo. The construction under the Public Works Administration grant of $892,920 was completed. These improvements include a brick exhibition building for small mammals and great apes; a stone exhibition building to house large mammals; a new wing to the bird house; a two-story building for machine and carpenter shops; a stone garage; the installation of three 250-horsepower down-draft boilers in the central heating plant; an extension of the conduit system to the small mammal house and large mammal house; and rearrangement of the electric supply distribution system, a portion of which was put underground.

The small mammal and great ape house was completed and opened to the public in May 1937. It is approximately 185 by 115 feet and contains 96 cages and tanks varying in size from 18 by 12 by 26 inches to 12 by 40 by 10 feet, which provide accommodations for a considerable variety of animals. The building consists of four sections: A large central room with cages in the center and around the sides, some with glass fronts and others with steel bars; a wing for the great apes with a glass partition between the animals and the public; a third room for the gibbons, which are likewise partitioned from the public by glass; and a fourth room, semicircular in form, which is termed the nocturnal room and is designed to house an array of small creatures that are rarely shown in collections. The building is fairly easy to keep clean, and the system of forced ventilation eliminates practically all the odor.

The contract work on the large mammal house was completed in June 1937, but considerable still remains to be done before it is ready for occupancy. This work is being carried on by the Zoo's regular personnel which it is hoped will be augmented by assistance from

W. P. A. It is anticipated that the building will be occupied by animals late in the summer of 1937.

The structure is about 227 by 90 feet and is designed to accommodate elephants, rhinos, hippos, pigmy hippos, tapirs, and giraffes, for which it has 13 inside cages ranging in size from 12 by 19 feet to 22 by 58 feet. Several of the inside cages have pools, and each cage connects with an outside yard in which the animals are retained by dry moats in lieu of fences. The design of the building is simple, well proportioned, and beautiful. The public space is 30 by 165 feet, and the sound-deadening effect of the acoustical tile on the ceiling produces a highly satisfactory condition. The walls of the cages for the hippo, African and Indian elephants, and giraffe have been painted with appropriate backgrounds by artists of the Treasury art relief project.

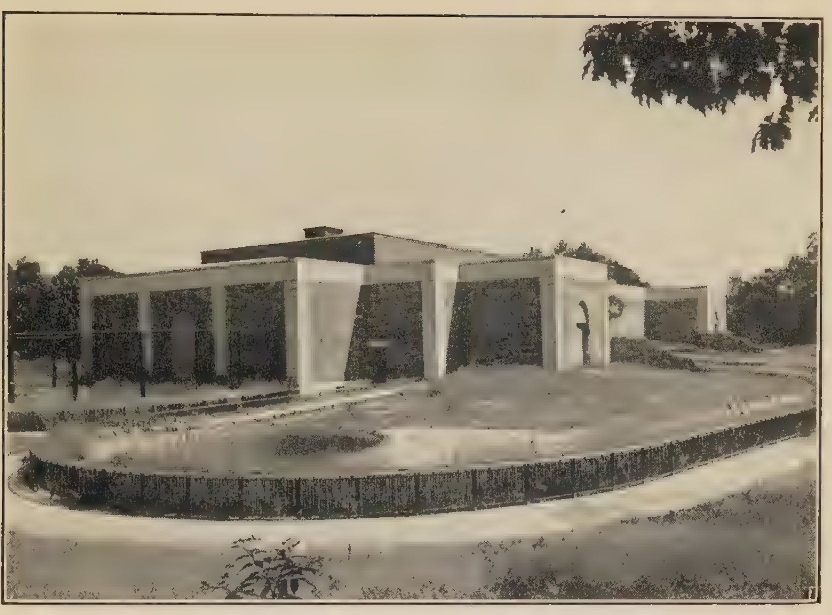
The addition to the bird house, 43 by 133 feet, was completed in November 1936. This wing contains 27 glass-fronted cages, one of which has insulated walls and a glass top and is provided with a refrigeration system which makes it a well-lighted cold storage room. This was stocked with penguins, which are thriving in the uniform temperature of 63° F. The backs of a number of the cages, including that of the penguin room, have been decorated with scenes representing various geographical regions, which greatly enhances the attractiveness of the exhibits. The art work was done by the Treasury art relief project.

The installation of new boilers in the central heating plant was completed late in the summer of 1936, and the plant was used during the winter of 1936–7.

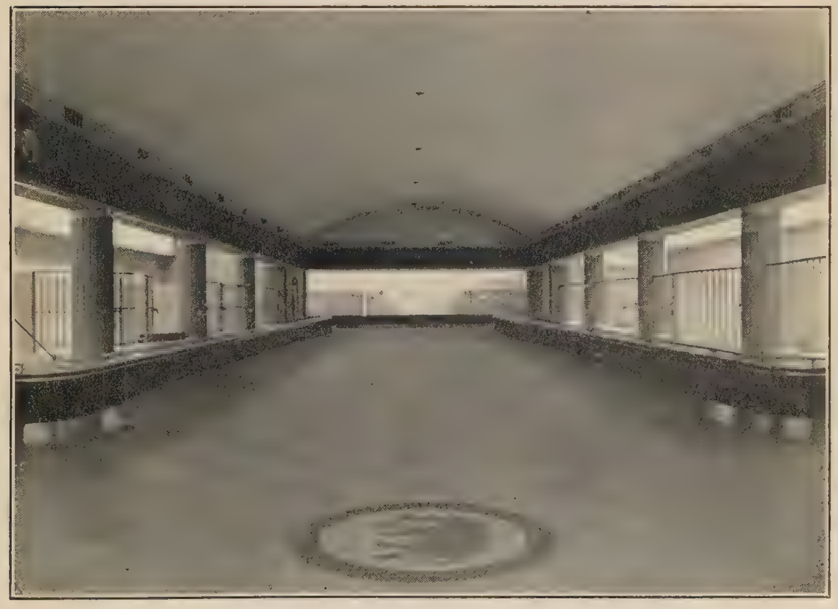
The mechanical shop building is of stone, 51 by 100 feet, 2 stories; the lower story accommodates a stockroom and iron and machine work, and the upper story is mainly for carpentry work. The improved facilities provided by this have permitted much greater efficiency of operations in the maintenance of the Park than had been possible heretofore.

The stone garage, 56 by 64 feet, was built near the boiler room and completed late in the summer of 1936.

From July 1, 1936, until January 27, 1937, a small and diminishing group of W. P. A. laborers was available for miscellaneous work about the Park. With this labor a variety of work was accomplished, including repairing and resurfacing some roads and walks. A trench 600 feet long was dug for the laying of electric conduit from the bird house to the large mammal house. Trenches also were dug for the laying of about 600 feet of sanitary sewers and drains. More than 400 cubic yards of sand was hauled from the creek bed, cleaned and screened for use in concrete work. Miscellaneous grading was

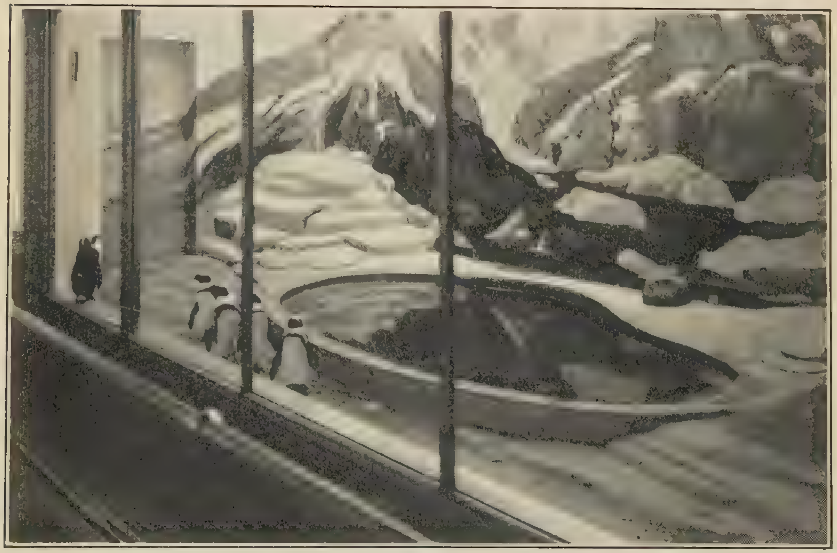


1. LARGE MAMMAL HOUSE AS SEEN FROM THE WEST. ELEPHANT YARD AND POOL IN FOREGROUND, AND GIRAFFE YARD AT LEFT.

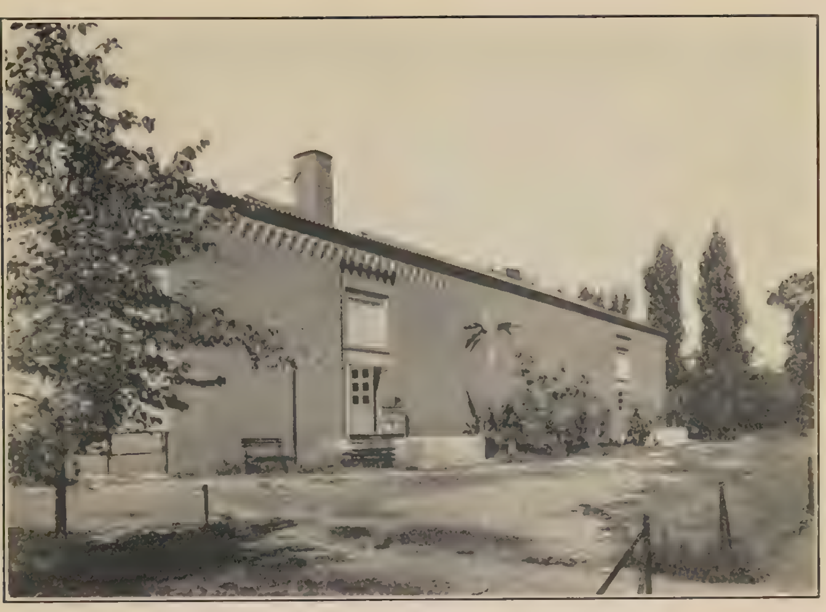


2. INTERIOR OF LARGE MAMMAL HOUSE LOOKING TOWARD HIPPO POOL.

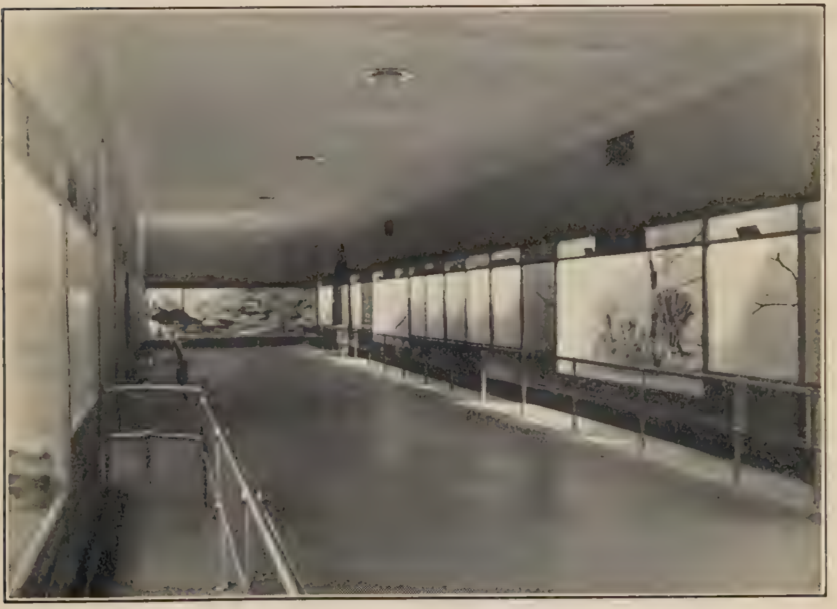
1. HIPPO IN POOL IN LARGE MAMMAL HOUSE.



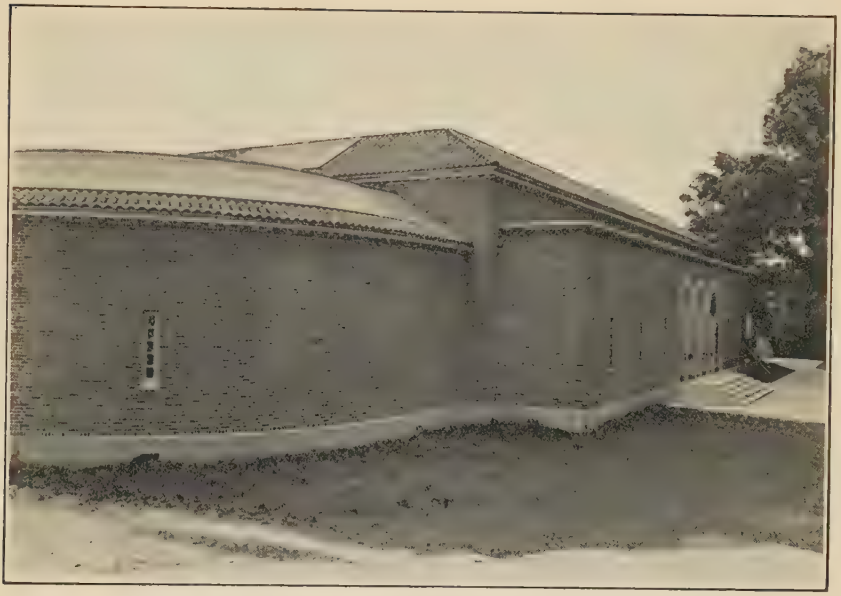
2. REFRIGERATED PENGUIN CAGE IN BIRD HOUSE.



1. EXTERIOR OF NEW ADDITION TO BIRD HOUSE.



2. INTERIOR OF NEW ADDITION TO BIRD HOUSE.



1. SMALL MAMMAL HOUSE AS SEEN FROM THE ROAD

2. INTERIOR OF NOCTURNAL ROOM OF SMALL MAMMAL HOUSE.

done about the Park. General improvement work about the grounds, including seeding, sodding, and planting of trees and shrubs, was carried on as well as the continuance of eradication of poison ivy in the sections of the Park most used by the public.

Normal maintenance operations of the Park required all the materials and personnel that could be supplied under the regular appropriation, so almost no improvements were made under the regular funds. Indeed, a great deal of finishing up work remains to be done around the newly constructed buildings or in them but is progressing very slowly because of lack of manpower and materials.

A bookbinder assigned to the Smithsonian Institution by the W. P. A. has bound, rebound, or repaired a considerable number of publications in the Zoo branch of the Smithsonian Institution library, resulting in a great improvement in the condition and usefulness of the library.

The work of classifying and arranging in their proper places in the library various publications of use in the Zoo has progressed very satisfactorily through the arrangement whereby a member of the Smithsonian Institution's regular library force comes to the Zoo once a week and carries out this type of work.

EXPEDITION

The National Geographic Society-Smithsonian Institution East Indies Expedition, which is financed by the National Geographic Society to obtain animals for this Zoo, left Washington in two sections. Dr. William M. Mann, Director of the Park, Mrs. Mann, and Dr. Maynard Owen Williams, chief of the foreign editorial staff of the National Geographic, left Washington January 12 and sailed from Vancouver, B. C., January 19 on the *Empress of Asia* for southern Asiatic points. On February 9, Roy Jennier, assistant head keeper, and Malcolm Davis, keeper, in the National Zoological Park, left Washington with 28 animals (2 black bears, 2 pumas, 2 jaguars, 4 raccoons, 3 opossums, 10 alligators, and 5 hellbenders), sailed from New York February 11 on the steamer *Talisse* and arrived at Belawan-Deli, Sumatra, March 22, 1937, where Dr. Mann had previously landed and had established headquarters for the expedition. The American animals were intended for zoos in the Far East. At the close of this fiscal year the expedition is still in the field, and it will not return to Washington until late in September or October 1937. Information as to the animal collection being assembled indicates a satisfactory trip.

NEEDS OF THE ZOO

The remaining two most important structural needs of the Zoo are a new antelope building and a new restaurant building.

The old frame structure now called the antelope house accommodates animals of a higher total value than any other single structure now occupied in the Park. It is an unhealthful type of structure, a dangerous fire hazard, is difficult to heat and expensive to maintain. A new building adapted for the magnificent and remarkable group of rather delicate even-toed hoofed creatures is much needed.

The old frame shelter now housing the restaurant and concession stand is badly deteriorated and entirely inadequate to accommodate the large volume of business that has developed with the increasing attendance at the Zoo. The construction of a suitable building would be a self-liquidating undertaking, as the annual revenue derived from the restaurant concession has been $6,012 per annum for the past 3 years, and for the forthcoming 3 years will be $9,012 per annum.

There is also need for some additional walks and roads that we hope may be constructed with the aid of the W. P. A.

VISITORS FOR THE YEAR

July	236, 500	February	95, 000
August	329, 400	March	176, 500
September	255, 500	April	239, 700
October	164, 400	May	318, 350
November	153, 450	June	265, 600
December	81, 250		
January	88, 450	Total	2, 435, 520

The attendance of organizations, mainly classes of students, of which there is definite record was 34,120 from 638 different schools in 20 States and the District of Columbia, as follows:

State	Number of persons	Number of parties	State	Number of persons	Number of parties
Alabama	20	1	North Carolina	1, 262	37
Connecticut	109	2	Ohio	934	26
Delaware	486	10	Pennsylvania	8, 552	167
District of Columbia	6, 638	132	Rhode Island	40	1
Georgia	363	11	South Carolina	234	7
Maine	107	2	Tennessee	16	1
Maryland	4, 659	75	Virginia	4, 870	85
Massachusetts	337	9	West Virginia	452	10
Michigan	86	2	Conventions—Members of various States	140	2
Missouri	46	1			
New Hampshire	72	1	Total	34, 120	638
New Jersey	2, 519	32			
New York	2, 178	24			

About 3 o'clock every afternoon, except Sundays and holidays, a census is made of the cars parked on the Zoo grounds. During the year 32,668 were so listed, representing every State in the Union, Canada, Mexico, Canal Zone, Alaska, and Cuba. Since the total number is merely a record of those actually parked at one time, it is not of value as indicating a total attendance but is of importance as showing the percentage attendance by States, Territories, and countries. The District of Columbia comprised slightly over 48 percent; Maryland, 21 percent; Virginia, 14 percent; and the remaining cars were from other States, Territories, and countries. During years in which counts have been made on Sunday as well as during the week it has been found that the percentage of cars from the District of Columbia, Maryland, and Virginia is less, and the percentage of the more distant States is correspondingly increased. This is brought about by tourists coming to the Zoo on Sundays when other points of interest are closed to them.

The nineteenth annual meeting of the American Society of Mammalogists was held in Washington May 4 to 8, inclusive. Their program included a trip to the Zoo on May 8, where luncheon was served in the large mammal house. The small mammal house was first opened to the public as this organization entered it.

ACCESSIONS

Gifts.—Many specimens were received as gifts this year. Interesting additions were a pair each of cheer pheasants and white-crested kaleege from Dr. J. Delacour, Cleres, France; a pair of blue-crowned hanging paroquets and a tui paroquet from Alan N. Steyne, Washington, D. C., and a male Kaibab squirrel from the United States Forest Service.

We take this opportunity to express appreciation for the assistance and cooperation of the personnel of the United States Biological Survey, National Park Service, and Forest Service, and Vernon Bailey, of Washington, D. C., Theodore Scheffer, of Puyallup, Wash., Alex Walker, of Tillamook, Oreg., and John M. Davis, of Arlington, Va., for gifts of American small mammals for stocking the small mammal house when it was opened. More than 150 small mammals were received through them from localities ranging from Georgia to Washington and Oregon.

When the small mammal and great ape house was completed, the Director of the Park was on an extended trip to the southern Asiatic region to assemble a collection for the Zoo, so it was not advisable, even if it had been financially possible, to stock this building with exotic animals. Arrangements were accordingly made for placing on exhibition a collection of American small mammals. It was probably the largest and best collection of its kind ever assembled, and has attracted much favorable attention. It is particularly valuable in showing the considerable diversity of forms common to North America and which are frequently overlooked or ignored.

Also, it is of value because it has given visitors an opportunity to study rather closely animals that are of great economic importance either because of their beneficial or destructive habits or their value for fur.

DONORS AND THEIR GIFTS

Mrs. Anna E. Anderson, Washington,. D. C., alligator.
A. M. Aytona, Washington, D. C., opossum.
L. D. Babbitt, Petersham, Mass., through Dr. Doris M. Cochran, copperhead snake, hog-nosed snake, spotted turtle, musk turtle.
Miss M. B. Bailey, Hyattsville, Md., 3 Pekin ducks.
Vernon Bailey, Washington, D. C., 3 flying squirrels, short-tailed shrew.
Mrs. John B. Baker, Durham, N. C., rhesus monkey.
Marshall Banks, Washington, D. C., screech owl.
Dr. Thos. Barbour, Cambridge, Mass., chicken snake, corn snake, 3 garter snakes, 2 black snakes, 2 king snakes, 15 water snakes.
Mrs. Virgil Barker, Fort Myers, Fla., broad-winged hawk.
Mrs. Beavers, Mt. Rainier, Md., black widow spider and eggs.
C. T. R. Bohannon, Carlsbad, N. Mex., prairie rattlesnake.
V. E. Bolton, Washington, D. C., opossum.
W. L. Bond, Fredericksburg, Va., 2 barn owls.
Julius Booker, C. C. C., Belvoir, Va., copperhead snake.
Miss Mary L. Borger, Chevy Chase, Md., white rabbit.
Harlie Branch, Washington, D. C., alligator.
R. D. Brands, Washington, D. C., groundhog.
Mrs. Richard Brickway, Washington, D. C., orange-fronted parrot.
Dr. Alice L. Brown, Washington, D. C., 18 black skimmers.
Miss Caroline Brown, Washington, D. C., alligator.
Elwood Brown, Washington, D. C., white-throated capuchin.
S. K. Brown, Eustis, Fla., 4 corn snakes, 2 pine snakes, 3 coral snakes, water moccasin.
Mrs. T. R. Brown, Washington, D. C., Belgian rabbit.
L. J. Burner, Maurertown, Va., raccoon.
Dr. A. Busk, Washington, D. C., 2 grass paroquets.
Miss Anna Butler, Washington, D. C., yellow-naped parrot.
Adjutant Carnahan, Washington, D. C., raccoon.
Dr. Doris M. Cochran, Washington, D. C., blacksnake.
Frederick Cochrane, Washington, D. C., alligator.
C. P. Coe, Chevy Chase, Md., raccoon.
Mrs. J. L. Cotton, Washington, D. C., Pekin duck.
Mrs. S. C. Cotton, Washington, D. C., 2 grass paroquets.
Mrs. J. M. Cox, Washington, D. C., 6 moles.
Raymond Crawford, Warren, Ohio, 2 sidewinder rattlesnakes, 2 chuckwalla lizards, gopher tortoise, 2 horn snakes, king snake.
C. R. Cruey, Centerville, Va., great white heron.
Frank Cundall, Kingston, Jamaica, Jamaica boa.
P. B. Darling, Washington, D. C., red fox.
Miss Priscilla Deane, Washington, D. C., bobwhite.
B. L. Deitzel, Washington, D. C., tarantula.
Dr. J. Delacour, Cleres, France, 2 cheer pheasants, 2 white-crested kaleege.
J. P. Delphey, Frederick, Md., Javan macaque, rhesus monkey.
Irving Denenberg, Washington, D. C., pied-billed grebe.
C. F. Denley, Glenmont, Md., 2 ring-necked pheasants, 2 white ring-necked pheasants.

Mario DePrato, Washington, D. C., 3 geckos, garter snake.
Mrs. Catherine L. Devine, Washington, D. C., alligator.
F. H. Dreyer, Laurel, Md., Cooper's hawk.
Vernon Dye, Alexandria, Va., barred owl.
Billy Earman, Washington, D. C., alligator.
Mrs. C. W. Elliott, Washington, D. C., double yellow-headed parrot.
Mrs. J. H. Elvin, Washington, D. C., 3 Pekin ducks.
Dr. Wm. O. Emory, Washington, D. C., 5 salamanders.
Mrs. Arnold Flack, Washington, D. C., 2 grass paroquets.
Florida Reptile Institute, Silver Springs, Fla., 2 red-shouldered hawks.
Dr. R. H. Ford, Washington, D. C., screech owl.
Mrs. C. R. Fornwald, Washington, D. C., screech owl.
Mrs. Agnes L. Fort, Washington, D. C., double yellow-headed parrot.
M. B. Foster, Orlando, Fla., corn snake, mud or horn snake.
Mrs. Edith Frazier, Washington, D. C., yellow-naped parrot.
C. B. Freeman, Washington, D. C., 4 screech owls.
R. L. George, King City, Calif., yellow-billed magpie.
Frank Glaisdell, Washington, D. C., 24 horned lizards.
Sol Gnatt, Washington, D. C., water moccasin.
W. R. Gorman, Washington, D. C., Pekin duck.
Louis Granados, Riverdale, Md., blacksnake.
Donald Griffin, Cambridge, Mass., 9 hibernating bats.
R. Grove, Washington, D. C., raccoon.
Joseph Gruss, Waldorf, Md., bald eagle.
Mrs. Emma T. Hahm, Washington, D. C., 3 fan-tailed pigeons.
Miss Matilda J. Hahn, Washington, D. C., alligator.
Miss Reba Haiden, Washington, D. C., alligator.
Hugh M. Hamill, Sells, Ariz., desert rattlesnake.
J. Harvey, Washington, D. C., Pekin duck.
Thaddeus Hess, Marine Band, Washington, D. C., 5 pygmy rattlesnakes, 5 Florida diamond-back rattlesnakes, 12 water moccasins, blacksnake, corn snake, 2 Florida king snakes, hoop snake or rainbow snake.
W. E. Hill, Petersburg, Va., banded rattlesnake.
P. J. Hollohan, Washington, D. C., Cuban parrot.
Mrs. N. Horan, Washington, D. C., African gray parrot.
L. C. Hosley, Washington, D. C., screech owl.
E. N. Hosmer, Arlington, Va., alligator.
Billy Householder, Phoenix, Ariz., Agassiz's tortoise.
Bob Householder, Phoenix, Ariz., Gila monster.
Tom Householder, Phoenix, Ariz., tarantula.
Dr. Claude Hudson, Washington, D. C., 18 red moon fish.
C. L. Hugh, Washington, D. C., opossum.
John H. Jackson, Oak Grove, Va., great horned owl.
W. B. Jones, Tuscaloosa, Ala., 2 water moccasins, 2 chicken snakes, copperhead snake.
Ellis S. Joseph, New York City, 10 banded finches.
L. S. Julier, Chevy Chase, Md., 2 Java sparrows.
Mrs. Martha Junkin, Washington, D. C., screech owl.
Wilbert Kaiser, Laurel, Md., bald eagle.
Walter Karig, Alexandria, Va., red-vented bulbul.
Mrs. A. S. Keever, Washington, D. C., ground squirrel.
Jacob W. Kennedy, Washington, D. C., tarantula.
C. T. Kettler, Washington, D. C., ribbon snakes.
J. B. Kimes, Silver Spring, Md., barn owl.

R. Lambert, Washington, D. C., 2 bobwhites.

Lester Leigh, Dade City, Fla., 3 garter snakes, chicken snake, 3 southern pilot snakes, 3 Florida king snakes, 3 mud or horned snakes.

M. Libert and Wm. Spawn, Washington, D. C., trap door spider and nest.

Letty L. Light, Washington, D. C., sparrowhawk.

Capt. G. E. Lightcap, Washington, D. C., barred owl.

Mr. and Mrs. F. C. Lincoln, Washington, D. C., salamander.

A. Loveridge, Cambridge, Mass., 2 chicken snakes, black snake, king snake, corn snake.

Rowland Lyon, Chevy Chase, Md., opossum.

W. Mackay, Washington, D. C., alligator.

E. B. Maddox, Hyattsville, Md., 2 raccoons.

Herbert Magruder, Washington, D. C., black snake.

Harry A. Mahone, Roanoke, Va., indigo snake.

Harold E. Martin, Washington, D. C., horseshoe crab.

Maryland University through Dr. Burhoe, 8 hairless rats.

H. W. D. Mayers, Collinsville, Conn., 2 green guenons.

R. H. McCauley, Ithaca, N. Y., 2 pine snakes, indigo snake.

Miss J. McDuffie, Washington, D. C., Pekin duck.

Mrs. J. D. McDuffie, Washington, D. C., Pekin duck.

E. A. McIlhenny, Avery Island, La., 10 wood ducks, black Carolina and turkey vulture hybrid.

Dr. Kenneth Meyers, Detroit, Mich., 5 lizards.

Mrs. Robert Montgomery, Washington, D. C., 2 horned lizards.

R. S. C. Morman, Washington, D. C., alligator.

Wesley McC. Morris, Ednor, Md., 2 Formosan ring-necked pheasants.

Miss F. C. Mortimer, Washington, D. C., screech owl.

E. C. Moyer, Washington, D. C., opossum.

Stanley Mulaik, Rio Grande City, Tex., through Dr. Doris M. Cochran, 2 scaly lizards.

Mrs. J. Murcelle, Washington, D. C., blue jay.

Miss Ann C. Murray, Cumberstone, Md., 2 gray foxes.

National Park Service, through A. E. Borell, Phoenix, Ariz., 12 desert pocket mice.

Mrs. E. Page, Washington, D. C., double yellow-head parrot.

Drury Parks, Washington, D. C., orange-crested cockatoo.

R. L. Parnell, Alexandria, Va., 2 great-horned owls.

Mrs. E. Penn, Washington, D. C., flying squirrel.

D. N. Pratt, Washington, D. C., mouse opossum.

L. C. Probert, Olney, Md., mute swan.

U. S. Randle, Randle Highlands, D. C., American black bear.

F. A. Rapp, Washington, D. C., great blue heron.

Miss Helen Roach, Washington, D. C., 2 Pekin ducks.

E. H. Rolston, Alexandria, Va., 2 gopher tortoises.

Carroll W. Ruhle, Washington, D. C., pilot snake, queen snake, water snake, 3 ring-necked snakes, worm snake.

Mrs. Charles Saltzman, Silver Spring, Md., 2 flying squirrels.

Andrew Santorios, Washington, D. C., 2 tarantulas.

James R. Sarton, Washington, D. C., alligator.

Earl Saunders, Washington, D. C., Canadian porcupine.

Edward Saunders, Kensington, Md., screech owl.

Theodore H. Scheffer, Puyallup, Wash., 4 yelm pocket mice, 2 mountain beavers, varying hare.

Dr. Schultz and Mr. Reid, Washington, D. C., pilot snake.
W. W. Schwink, Washington, D. C., woodchuck.
Harry Sedley, Washington, D. C., marine turtle.
Miss Carolyn Sheldon, Woodstock, Vt., 2 eastern chipmunks.
W. H. Sherbert, Edgewater, Md., red-shouldered hawk.
John Shorey, Washington, D. C., screech owl.
G. W. Shuster, Washington, D. C., baby raccoon.
Allen Smith, Washington, D. C., 2 fence lizards.
Miss Betty Smith, Washington, D. C., white rabbit.
Miss Daisy Smith, Newark, Del., ferret.
Otto Smith, Harpers Ferry, W. Va., gray fox.
Wm. Spawn and M. Libert, Washington, D. C., trap door spider and nest.
Miss Daisy R. Spradling, Athens, Tenn., osprey or fish hawk.
Miss Katherine Stafford, Baltimore, Md., white-throated capuchin, marmoset.
F. F. Stayton, Chestertown, Md., brown capuchin.
Alan N. Steyne, Washington, D. C., 2 blue-crowned hanging paroquets, Tui paroquet.
H. F. Stroup, Washington, D. C., grivet monkey.
J. J. Talcott, Washington, D. C., horned lizard.
Dr. W. M. Tallant, Manatee, Fla., indigo snake.
Ralph Taylor, Washington, D. C., black widow spider.
Mrs. S. G. Taylor, Washington, D. C., yellow-naped parrot.
M. R. Thorp, Washington, D. C., double-yellow-headed parrot.
Mrs. Ethel B. Timmons, Washington, D. C., Pekin duck.
Miss Mary Troiano, Washington, D. C., salamander.
Carl Tucker, Washington, D. C., hog-nosed snake.
Horace A. Tucker, Washington, D. C., indigo snake.
U. S. Biological Survey, through C. E. Beebe, St. Regis, Mont., puma; through J. S. C. Boswell, Washington, D. C., 3 corn snakes; through H. N. Elliott, El Paso, Tex., 9 prairie dogs, 6 pocket gophers; through J. Finley and C. E. McFarland, Cashmere, Wash., 3 mantled ground squirrels, 5 Hollister chipmunks; through John H. Gatlin, Albuquerque, N. Mex., puma, 2 prairie wolves; through Gill Gigstead, Havana, Ill., 4 coyotes; through A. S. Hamm and N. E. Buell, Casper, Wyo., long-tailed weasel, 2 picket-pin gophers; through L. E. Hicks and L. Baumgartner, Columbus, O., 4 red squirrels; through F. N. Jarvis, Washington, D. C., 3 meadow mice, pied-billed grebe; through E. V. Komarek, Thomasville, Ga., opposum, 3 cotton rats; through Kenneth Krumm, Middle River, Minn., muskrat; through C. R. Landon, San Antonio, Tex., 4 Baird wood rats, 4 cotton rats, 3 Rio Grande ground squirrels, hispid pocket mouse; through C. R. Landon and J. M. Hill, Jr., Bryan, Tex., 6 pocket gophers; through C. R. Landon and L. C. Whitehead, San Antonio, Tex., Baird wood rat, cotton rat, hispid pocket mouse, 2 gray pigmy mice, 3 Merriam's silky pocket mice, 2 nine-banded armadillos, 3 pallid white-footed mice, ground squirrel, red house mouse; through J. Manweiler, Baudette, Minn., 6 varying hares or snowshoe rabbits; through Wm. H. Marshall, Bingham, Utah, 3 marmots; through O. J. Murie, Seattle, Wash., bald eagle, glaucous-winged gull; through C. E. Mushback, Cache, Okla., 8 prairie dogs, 2 cotton rats, 2 round-tail wood rats, Old field mouse; through W. D. Parker, Fort Totten, N. Dak., 6 flag squirrels, 11 Richardson ground squirrels; through W. Taylor and V. W. Lehmann, Eagle Lake, Tex., 7 Texan red wolves; through H. W. Terhune, DeWitt, Ark., 6 cotton rats; through Stanley Young, Washington, D. C., bay lynx.
U. S. Forest Service, Washington, D. C., Kaibab squirrel.
W. C. Varner, Washington, D. C., horseshoe crab.

Dr. Charles T. Vorhies, Tucson, Ariz., 2 Merriam kangaroo rats.
Alex Walker, Tillamook, Ore., Washington varying hare, Oregon creeping mouse.
Col. W. E. Welliver, Washington, D. C., 2 African monitors.
P. C. Wercks, Washington, D. C., grass paroquet.
W. David White, Washington, D. C., 3 red-shouldered hawks.
Mrs. J. H. Whitmore, Washington, D. C., yellow-naped parrot.
L. Wilkins, Takoma Park, Md., banded rattlesnake.
Mrs. B. F. Williams, Chevy Chase, Md., Canadian porcupine.
G. B. Williams, Thurmont, Md., 12 banded rattlesnakes, 10 copperheads, 5 water snakes, 2 hog-nosed snakes, 11 pilot snakes, 2 fence lizards.
Mrs. R. Williams, Washington, D. C., alligator.
R. W. Williams, Washington, D. C., 2 rhesus monkeys.
E. W. Wilson, Washington, D. C., groundhog.
Lee Guy Wilson Estate, Tree Top, Va., barred owl.
John Wyman, Washington, D. C., duck.
Philip N. Youtz, New York City, kinkajou.
Yugoslav Legation, Washington, D. C., alligator.

Births.—There were 50 mammals born, 37 birds hatched, and 14 reptiles hatched or born in the Park during the year. These include the following:

MAMMALS

Scientific name	Common name	*Number*
Ammotragus lervia	Aoudad	3
Axis axis	Axis deer	3
Bison bison	American bison	2
Bos frontalis	Gayal	2
Bos indicus	Zebu	1
Camelus dromedarius	Arabian camel	1
Canis lupus lycaon	Timber wolf	2
Capromys pilorides	Hutia	3
Cervus elaphus	Red deer	2
Dama dama	Fallow deer	8
Dolichotis salinicola	Dwarf cavy	4
Equus przewalskii	Mongolian wild horse	1
Erethizon dorsatum	Eastern porcupine	1
Felis onca	Jaguar	3
Lama glama	Llama	3
Mephitis nigra	Common skunk	1
Oryx beisa annectens	Ibean beisa oryx	1
Sika nippon	Japanese deer	8
Ursus gyas	Alaska Peninsula bear	1

BIRDS

Anas undulata	African yellow-billed duck	1
Ardea herodius×*A. occidentalis*	Heron hybrid	3
Branta canadensis	Canada goose	2
Chrysolophus pictus	Golden pheasant	5
Larus novaehollandiae	Silver gull	14
Pavo cristatus	Peafowl	5
Streptopelia risoria	Ring-necked dove	2

REPTILES

Boa canina	Green tree boa	6
Egernia cunninghami	Cunningham skink	2
Sistrurus catenatus catenatus	Massasauga	6

Exchanges.—In an exchange with the Philadelphia Zoological Gardens there were received the following: Hybrid tree kangaroo, American elk or wapiti, 2 European water snakes, 4 European vipers, 6 green tree frogs, and 10 small European lizards. From Louis Ruhe, Inc., New York City, were received a cock of the rock and a koel. A pair of gannets was received from the Toronto Park Zoo, Toronto, Canada. From Dr. Johan Beetz, Director, Service de l'Élevage des Animaux a' Fourrure, Province of Quebec, was received a splendid specimen of ranch-bred mink obtained by him from the mink farm of Dr. J. E. La Forest, near the city of Quebec.

Purchases.—Important purchases during the year were three pronghorn antelopes, 6 jackass penguins, a pair of jabiru storks, and 3 black-tailed marmosets. In December 1936, 30 hummingbirds were purchased in Habana, Cuba, and transported by airplane to the Park. Only 2 died en route, the remainder arriving in good condition.

REMOVALS

Deaths.—Important losses by death during the year include two chimpanzees, one of which, "Soko", had been in the collection since September 8, 1915. A Komodo dragon received June 21, 1934, died July 11, 1937. A Burmese deer and saiga antelope died during this period.

During the year 405 specimens that died were sent to the National Museum.

ANIMALS IN COLLECTION THAT HAD NOT PREVIOUSLY BEEN EXHIBITED

MAMMALS

Scientific name	*Common name*
Callithrix argentata	Black-tailed marmoset.
Cricetomys gambianus	African pouched rat.

BIRDS

Catreus wallichii	Cheer pheasant.
Gennaeus albocristatus	White-crested kaleege.

REPTILES

Epicrates subflavus	Jamaica boa.

Statement of accessions

Class	Presented	Born	Received in exchange	Purchased	On deposit	Total
Mammals	185	50	3	26	15	279
Birds	97	37	26	204	18	382
Reptiles	224	14	16	36	25	315
Amphibians	7		6	19		32
Fishes			50			50
Arachnids	6					6
Crustaceans	2					2
Insects	1					1
Total	522	101	101	285	58	1, 067

Summary

Animals on hand July 1, 1936	2, 191
Accessions during the year	1, 067
Total animals in collection during year	3, 258
Removal from collection by death, exchange, and return of animals on deposit	916
In collection June 30, 1937	2, 342

Status of collection

Class	Species	Individuals	Class	Species	Individuals
Mammals	200	644	Insects	1	50
Birds	313	890	Mollusks	1	1
Reptiles	127	438	Crustaceans	1	1
Amphibians	30	150			
Fishes	26	159	Total	701	2, 342
Arachnids	2	9			

ANIMALS IN THE NATIONAL ZOOLOGICAL PARK, JUNE 30, 1937

MAMMALS

MARSUPIALIA

		Number
Didelphidae:		
Didelphis virginiana	Opossum	9
Metachirus opossum	Zorro or banana opossum	1
Macropodidae:		
Dendrolagus ursinus×*D. inustus*	Hybrid tree kangaroo	1

CARNIVORA

Felidae:		
Felis concolor azteca	Mexican puma	1
Metachirus opossum	Puma	4
Felis leo	Lion	6
Felis ocreata	Uganda wild tabby	1
Felis onca	Jaguar	5
	Black jaguar	2
Felis pardus	Black leopard	1
Felis pardus suahelicus	East African leopard	1
Felis temmincki	Golden cat	1
Felis tigris longipilis	Siberian tiger	2

Felidae—Continued.		
Felis tigris sondaicus	Sumatran tiger	2
Lynx baileyi	Bailey's lynx	1
Lynx caracal	Caracal	1
Lynx rufus	Bay lynx	5
Viverridae:		
Civettictis civetta	Civet	1
Genetta dongalana neumanni	Neumann's genet	1
Moschothera megaspila	Civet	3
Hyaenidae:		
Crocuta crocuta germinans	East African spotted hyena	1
Hyaena brunnea	Brown hyena	2
Canidae:		
Canis latrans	Coyote	13
	Albino coyote	1
Canis latrans × *domestica*	Coyote and dog hybrid	2
Canis lupus lycaon	Timber wolf	4
Canis lupus nubilus	Wolf	8
Canis lupus nubilus × *domesticus*	Wolf and dog hybrid	1
Canis rufus	Texan red wolf	7
Chrysocyon jubata	Maned wolf	1
Urocyon cinereoargenteus	Gray fox	7
Vulpes fulva	Red fox	9
Procyonidae:		
Nasua narica	Gray coatimundi	3
Potos flavus	Kinkajou	3
Procyon cancrivorus	Crab-eating raccoon	1
Procyon lotor	Raccoon	17
	Albino raccoon	1
	Black raccoon	1
Bassariscidae:		
Bassariscus astutus	Ring-tail or cacomistle	2
Mustelidae:		
Galictis barbara barbara	White tayra	2
Lutra canadensis vaga	Florida otter	2
Mellivora capensis	Ratel	1
Mephitis nigra	Skunk	7
Mustela cicognani cicognani	Bonaparte's weasel	1
Mustela eversmanni	Ferret	3
Mustela longicauda longicauda	Long-tailed weasel	1
Mustela vison vison	Mink	1
Spilogale ambarvalis	Florida spotted skunk	1
Ursidae:		
Euarctos americanus	American black bear	6
Euarctos emmonsii	Glacier bear	1
Helarctos malayanus	Malay or sun bear	1
Thalarctos maritimus	Polar bear	2
Thalarctos maritimus × *Ursus gyas*	Hybrid bear	3
Ursus arctos	European brown bear	4
Ursus gyas	Alaska Peninsula brown bear	4
Ursus kidderi	Kidder's bear	2
Ursus middendorffi	Kodiak bear	3
Ursus sitkensis	Sitka brown bear	3
Ursus thibetanus	Himalayan bear	1

PINNIPEDIA

Otariidae:		
Eumetopias jubatus	Steller's sea lion	1
Zalophus californianus	California sea lion	2
Phocidae:		
Phoca richardii	Pacific harbor seal	3

PRIMATES

Callitrichidae:		
Callithrix jacohus	Common marmoset	1
Mico argentata	Black-tailed marmoset	3
Oedipomidas geoffroyi	Central American marmoset	1
Cebidae:		
Cebus apella	Brown capuchin	1
Cebus capucinus	White-throated capuchin	5
Cebus fatuella	Weeping capuchin	4
Cebus sp	Brown capuchin	2
Cercopithecidae:		
Cercocebus fuliginosus	Sooty mangabey	5
Cercopithecus albigularis	Syke's guenon	2
Cercopithecus aethiops aethiops	Grivet monkey	1
Cercopithecus aethiops roloway	Roloway monkey	1
Cercopithecus aethiops sabaeus	Green guenon	4
Cercopithecus diana	Diana monkey	1
Cercopithecus neglectus	De Brazza's guenon	1
Cercopithecus petaurista	Lesser white-nosed guenon	2
Colobus polycomos caudatus	White-tailed guereza	1
Colobus polycomos polycomos	White-tailed colobus	1
Macaca fuscata	Japanese monkey	2
Macaca mordax	Javan macaque	3
Macaca mulatta	Rhesus monkey	13
Macaca silenus	Wanderoo monkey	2
Macaca sinica	Bonnet monkey	1
Macaca sp	Macaque monkey	1
Magus maurus	Moor monkey	1
Mandrillus leucophaeus	Drill	1
Mandrillus sphinx	Mandrill	3
Papio comatus	Chacma	2
Papio hamadryas	Hamadryas baboon	1
Papio papio cynocephalus	East African baboon	2
Papio papio papio	West African baboon	1
Theropithecus gelada	Gelada baboon	1
Hylobatidae:		
Symphalangus syndactylus	Siamang gibbon	1
Pongiidae:		
Pongo abelii	Sumatran orangutan	1

RODENTIA

Sciuridae:		
Callospermophilus saturatus	Mantled ground squirrel	2
Citellus beecheyi douglassii	Douglas ground squirrel	1
Citellus mexicanus parvidens	Rio Grande ground squirrel	3
Citellus richardsonii	Richardson ground squirrel	9

Sciuridae—Continued.		
Citellus richardsonii elegans	Picket-pin gopher	1
Citellus tridecemlineatus	Flag squirrel	6
Cynomys ludovicianus	Prairie dog	13
Eutamias amoenus ludibundus	Hollister chipmunk	2
Glaucomys volans	Flying squirrel	5
Marmota flaviventris	Marmot or whistler	3
Marmot monax	Woodchuck or groundhog	7
	Albino woodchuck or groundhog	1
Sciurus finlaysoni	Lesser white squirrel	2
Sciurus hoffmani sub. sp	Hoffman's squirrel	2
Sciurus kaibabensis	Kaibab squirrel	1
Sciurus niger	Fox squirrel	1
Tamias striatus	Eastern chipmunk	2
Tamiasciurus hudsonicus	Red squirrel	2
Geomyidae:		
Geomys arenarius	Sand pocket gopher	4
Thomomys douglasii yelmensis	Yelm pocket gopher	1
Heteromyidae:		
Perognathus hispidus	Hispod pocket mouse	1
Perognathus merriami merriami	Merriam's silky pocket mouse	2
Perognathus penicilliatus	Desert pocket mouse	2
Castoridae:		
Castor canadensis	Beaver	2
Cricetidae:		
Baiomys taylori taylori	Gray pigmy mouse	1
Microtus oregoni oregoni	Oregon creeping mouse	1
Microtus pennsylvanicus	Meadow mouse	2
Neotoma floridana attwateri	Round-tailed wood rat	2
Neotoma micropus	Baird wood rat	2
Ondatra zibethica	Black muskrat	1
Peromyscus leucopus	White-footed mouse	4
Peromyscus maniculatus pallescens	Pallid white-footed mouse	2
Sigmodon hispidus hispidus	Cotton rat	9
Sigmodon hispidus texianus	Cotton rat	5
Muridae:		
Cricetomys gambianus	Gambia pouched rat	2
Mus musculus	Red house mouse	2
Mus wagneri	Waltzing mouse	3
Rattus domestica	Hairless rat	4
Dipodidae:		
Dipodomys merriami	Merriam kangaroo rat	2
Hystricidae:		
Acanthion brachyurum	Malay porcupine	2
Hystrix galeata	East African porcupine	2
Erethizontidae:		
Erethizon dorsatum	Eastern porcupine	1
Myocastoridae:		
Myocastor coypu	Coypu rat	2
Capromyidae:		
Capromys pilorides	Hutia	9
Cuniculidae:		
Citellus richardsonii	Central American paca	2

Dasyproctidae:		
Dasyprocta croconota prymnolopha	Agouti	2
Dasyprocta rubrata	Trinidad agouti	2
Myoprocta sp	Tailed agouti	1
Caviidae:		
Cavia porcellus	Domestic guinea pig	6
Dolichotis magellanica	Patagonian cavy	1
Dolichotis salinicola	Dwarf cavy	2
Hydrochoeridae:		
Hydrochoerus hydrochoerus	Capybara	1
LAGOMORPHA		
Leporidae:		
Lepus americanus	Varying hare or snowshoe rabbit	1
Oryctolagus cuniculus	Domestic rabbit	2
	Angora rabbit	1
ARTIODACTYLA		
Bovidae:		
Ammotragus lervia	Aoudad	11
Anoa depressicornis	Anoa	1
Antilope cervicapra	Black buck or Indian antelope	1
Bison bison	American bison	21
Bos frontalis	Gayal	4
Bos indicus	Zebu	4
Boselaphus tragocamelus	Nilgai	1
Bubalus bubalis	Indian buffalo	1
Capra sibirica	Siberian ibex	1
Connochaetes gnu	White-tailed gnu	2
Connochaetes taurinus albojubatus	White-bearded gnu	2
Hemitragus jemlahicus	Tahr	5
Onotragus lechee	Lechee antelope	1
Oryx beisa annectens	Ibean beisa oryx	3
Ovis europaeus	Mouflon	5
Poephagus grunniens	Yak	4
Taurotragus oryx	Eland	2
Antilocapridae:		
Antilocapra americana	Pronghorn antelope	3
Cervidae:		
Axis axis	Axis deer	8
Cervus canadensis	American elk	3
Cervus duvaucellii	Barasingha deer	4
Cervus elaphus	European red deer	18
Cervus xanthopygus	Bedford deer	2
Dama dama	Fallow deer	16
	White fallow deer	19
Muntiacus sinensis	Barking or rib-faced deer	1
Odocoileus costaricensis	Costa Rican deer	2
Odocoileus virginianus	Virginia deer	3
Rusa moluccensis	Molucca deer	2
Sika nippon	Japanese deer	23
Camelidae:		
Camelus bactrianus	Bactrian camel	1
Lama glama	Llama	10
Lama huanacus	Guanaco	2

Tayassuidae:		
Pecari angulatus	Collared peccary	3
Tayassu pecari	White-lipped peccary	2
Suidae:		
Babirussa alfurus	Babirussa	2
Phacochoerus aethiopicus massaicus	East African warthog	3
Sus scrofa	European wild boar	1
Hippopotamidae:		
Choeropsis liberiensis	Pigmy hippopotamus	2
Hippopotamus amphibius	Hippopotamus	1

PERISSODACTYLA

Equidae:		
Equus grevyi	Grevy's zebra	1
Equus grevyi-asinus	Zebra-ass hybrid	1
Equus grevyi-caballus	Zebra-horse hybrid	1
Equus onager	Asiatic wild ass or kiang	2
Equus przewalskii	Mongolian wild horse	3
Equus quagga chapmani	Chapman's zebra	8
Equus zebra	Mountain zebra	2
Tapiridae:		
Tapirella bairdii	Baird's tapir	1
Tapirus terrestris	Brazilian tapir	1
Rhinocerotidae:		
Diceros bicornis	Black rhinoceros	1

PROBOSCIDEA

Elephantidae:		
Elephas sumatranus	Sumatra elephant	1
Elephas maximus	Indian elephant	1
Loxodonta africana oxyotis	African elephant	1

EDENTATA

Choloepodidae:		
Choloepus didactylus	Two-toed sloth	4
Dasypodidae:		
Dasypus novemcinctus	Nine-banded armadillo	4

CHIROPTERA

Desmodontidae:		
Desmodus rotundus	Trinidad vampire bat	3

Birds

STRUTHIONIFORMES

Struthionidae:		
Struthio camelus	South African ostrich	1

RHEIFORMES

Rheidae:		
Rhea americana	Common rhea or nandu	1

CASUARIIFORMES

Casuariidae:		
Casuarius unappendiculatus	Single-wattled cassowary	1
Dromiceiidae:		
Dromiceius n. hollandiae	Common emu	1

SPHENISCIFORMES

Spheniscidae:		
Spheniscus demersus	Jackass penguin	6

PELECANIFORMES

Pelecanidae:		
Pelecanus californicus	California brown pelican	2
Pelecanus conspicillatus	Australian pelican	1
Pelecanus erythrorhynchos	American white pelican	7
Pelecanus erythrorhynchos × *P. occidentalis*	Hybrid pelican	1
Pelecanus occidentalis	Brown pelican	5
Pelecanus onocrotalus	European pelican	2
Pelecanus roseus	Rose-colored pelican	2
Sulidae:		
Morus bassanus	Gannet	2
Sula granti	Blue-footed booby	1
Phalacrocoracidae:		
Nannopterum harrisi	Flightless cormorant	2
Phalacrocorax auritus albociliatus.	Farallon cormorant	2
Phalacrocorax auritus floridanus	Florida cormorant	1
Anhingidae:		
Anhinga anhinga	Anhinga	2

CICONIIFORMES

Ardeidae:		
Ardea herodias	Great blue heron	1
Ardea herodias × *A. occidentalis*	Hybrid heron	4
Ardea occidentalis	Great white heron	1
Casmerodius albus egretta	American egret	2
Nycticorax nycticorax naevius	Black-crowned night heron	15
Cochleariidae:		
Cochlearius cochlearius	Boatbill heron	3
Balaenicipitidae:		
Balaeniceps rex	Shoe-bill stork	1
Scopidae:		
Scopus umbretta	Hammerhead	1
Ciconiidae:		
Dissoura episcopus	Woolly-necked stork	1
Ephippiorhynchus senegalensis	Saddle-billed stork	1
Jabiru mycteria	Jabiru	2
Leptoptilus crumeniferus	Marabou	1
Leptoptilus dubius	Indian adjutant	1
Leptoptilus javanicus	Lesser adjutant	2
Mycteria americana	Wood ibis	1

Threskiornithidae:

Ajaia ajaja	Roseate spoonbill	1
Guara alba	White ibis	4
Guara alba × *G. rubra*	Hybrid ibis	1
Guara rubra	Scarlet ibis	2
Threskiornis aethiopica	Sacred ibis	2
Threskiornis melanocephala	Black-headed ibis	2

ANSERIFORMES

Anatidae:

Aix sponsa	Wood duck	18
Alopochen aegyptiacus	Egyptian goose	2
Anas domestica	Peking duck	15
Anas platyrhynchos	Mallard	35
	Call duck (white)	1
Anas rubripes	Black or dusky mallard	2
Anas undulata	African yellow-billed duck	8
Anser albifrons	American white-fronted goose	3
Anser fabalis	Bean goose	2
Branta bernicla	Brant	3
Branta canadensis	Canada goose	6
Branta canadensis hutchinsii	Hutchin's goose	4
Branta canadensis minima	Cackling goose	4
Branta canadensis occidentalis	White-cheeked goose	20
Branta leucopsis	Barnacle goose	1
Cairina moschata	Muscovy duck	3
Casarca variegata	Paradise duck	1
Cereopsis novaehollandiae	Cereopsis or Cape Barren goose	1
Chen atlantica	Snow goose	7
Chen caerulescens	Blue goose	9
Chloephaga leucoptera	Magellan goose	1
Cygnopsis cygnoides	Chinese goose	1
Cygnus columbianus	Whistling swan	3
Cygnus olor	Mute swan	8
Dafila acuta	Pintail duck	5
Dafila bahamensis	Bahaman pintail	1
Dafila acuta × *D. sp*	Pintail hybrid	1
Dendrocygna arborea	Black-billed duck	5
Dendrocygna autumnalis	Black-bellied tree duck	4
Dendrocygna viduata	White-faced tree duck	1
Leptotarsis eytoni	Eyton's tree duck	1
Mareca americana	Bald pate	3
Neochen jubata	Orinoco goose	1
Nettion carolinense	Green-winged teal	1
Nyroca collaris	Ring-neck duck	1
Nyroca valisineria	Canvas-back duck	1
Philacte canagica	Emperor goose	11
Plectropterus gambensis	Spur-winged goose	1
Querquedula cyanoptera	Cinnamon teal	1
Querquedula discors	Blue-winged teal	1
Sarkidiornis melanota	Comb duck	1
Tadorna tadorna	Shelldrake	1

FALCONIFORMES

Cathartidae:

Cathartes aura	Turkey vulture	3
Cathartes aura × *Coragyps atratus*	Black Carolina and turkey vulture hybrid	1
Coragyps atratus	Black vulture	1
Gymnogyps californianus	California condor	3
Vultur gryphus	South American condor	1

Accipitridae:

Aegypius monachus	Cinereous vulture	1
Aquila chrysaetos	Golden eagle	2
Buteo borealis	Red-tailed hawk	5
Buteo lineatus	Red-shouldered hawk	3
Buteo platypterus	Broad-winged hawk	1
Buteo swainsoni	Swainson's hawk	1
Gypaetus barbatus grandis	Lammergeyer	1
Gyps rueppelli	Ruppell's vulture	1
Haliastur indus	Malay brahminy kite	1
Haliaeetus leucocephalus	Bald eagle	20
Milvus migrans	Yellow-billed kite	1
Pandion haliaetus carolinensis	Osprey or fish hawk	2
Stephanoaetus coronatus	Crowned hawk eagle	1
Torgos tracheliotus	African eared-vulture	1
Uroaetus audax	Wedge-tailed eagle	1

Falconidae:

Falco sparverius	Sparrow hawk	1
Polihierax semitorquatus	African pigmy falcon	3
Polyborus cheriway	Audubon's caracara	2
Polyborus plancus	South American caracara	1

GALLIFORMES

Cracidae:

Crax globulosa	Spix's wattled curassow	1
Crax rubra	Panama curassow	1
Mitu mitu	Razor-billed curassow	1
Mitu salvini	Salvin's curassow	1

Phasianidae:

Argusianus argus	Argus pheasant	1
Calophasis ellioti	Elliot's pheasant	1
Catreus wallichii	Cheer pheasant	1
Chrysolophus amherstiae	Lady Amherst's pheasant	3
Chrysolophus amherstiae × *Syrmaticus reevesi*	Hybrid	1
Chrysolophus pictus	Golden pheasant	5
Colinus virginianus	Bobwhite	1
Coturnix japonica	Asiatic migratory quail	3
Crossoptilon mantchuricum	Manchurian pheasant	2
Gennaeus albocristatus	White-crested kaleege	1
Gennaeus lineatus	Lineated pheasant	3
Gennaeus nycthemerus	Silver pheasant	2
Gennaeus nycthemerus bellii	Bell's silver pheasant	1
Hierophasis swinhoei	Swinhoe's pheasant	2

Phasianidae—Continued.		
Lophophorus impeyanus	Himalayan Impeyan pheasant	2
Pavo cristatus	Blue peafowl	7
	White peafowl	1
Pavo muticus	Green peafowl	2
Phasianus torquatus	Ring-necked pheasant	4
	White ring-necked pheasant	2
Phasianus torquatus formosanus	Formosan ring-necked pheasant	2
Syrmaticus reevesi	Reeve's pheasant	2
Numididae:		
Numida mitrata reichenowi	Reichenow's helmeted guinea fowl	1
Meleagrididae:		
Meleagris gallopavo	Domestic turkey	1

GRUIFORMES

Gruidae:		
Anthropoides virgo	Demoiselle crane	3
Antigone australasiana	Australian crane	1
Balearica pavonina	West African crowned crane	1
Balearica regulorum gibbericeps	East African crowned crane	1
Grus canadensis canadensis	Little brown crane	1
Grus canadensis tabida	Sandhill crane	1
Grus leucauchen	White-naped crane	1
Grus leucogeranus	Siberian crane	2
Psophiidae:		
Psophia crepitans	Gray-backed trumpeter	1
Rallidae:		
Fulica americana	American coot	1
Gallinula chloropus cachinnans	Florida gallinule	1
Limnocorax flavirostra	African black rail	3
Porphyrio melanotus	New Zealand mud hen	1
Porphyrio poliocephalus	Gray-headed porphyrio	2
Eurypygidae:		
Eurypyga helias	Sun bittern	2
Otididae:		
Otis cafra	Denham's bustard	1
Otis caffra jacksoni	Jackson's bustard	1

CHARADRIIFORMES

Haematopodidae:		
Haematopus ostralegus	European oyster catcher	2
Charadriidae:		
Belonopterus cayennensis	South American lapwing	1
Sarciophorus tectus	Black-headed plover	1
Scolopacidae:		
Philomachus pugnax	Ruff	2
Laridae:		
Larus argentatus	Herring gull	2
Larus delawarensis	Ring-billed gull	5
Larus glaucescens	Glaucous-winged gull	1
Larus novaehollandiae	Silver gull	60
Larus occidentalis	Western gull	1
Larus ridibundus	European gull	1

COLUMBIFORMES

Pteroclidae:		
Pterocles orientalis	Oriental sandgrouse	2
Columbidae:		
Caloenas nicobarica	Nicobar pigeon	1
Columba leuconota	Tibetan pigeon	2
Columba palumbus	Wood pigeon	2
Columba, domestic variety	Archangel pigeon	2
Columba, domestic variety	Fan-tailed pigeon	3
Goura victoria	Victoria crowned pigeon	2
Leptotila rufaxilla	Scaled pigeon	1
Streptopelia risoria	Ring-necked dove	7
Streptopelia senegalensis	East African ring-necked dove	1
Turtur risorius	Turtle dove	1
Zenaidura macroura macroura	West Indian dove	1

PSITTACIFORMES

Loriidae:		
Eos rubra	Red lory	1
Trichoglossus cyanogrammus	Green-naped lory	1
Trichoglossus forsteni	Forsten's paroquet	1
Trichoglossus novaehollandiae	Blue-bellied lory	1
Psittacidae:		
Agapornis lilianae	Nyassa lovebird	2
Amazona albifrons	White-fronted parrot	4
Amazona amazonica	Orange-winged parrot	2
Amazona arausiaca	Bouquet's parrot	1
Amazona auropalliata	Yellow-naped parrot	9
Amazona farinosa	Mealy parrot	1
Amazona festiva	Festive parrot	1
Amazona leucocephala	Cuban parrot	2
Amazona ochrocephala	Orange-fronted parrot	2
Amazona ochroptera	Yellow-shouldered parrot	3
Amazona oratrix	Double yellow-head parrot	7
Amazona sp	Red-fronted parrot	1
Amazona ventralis	Hispaniolan white-fronted parrot	1
Amazona viridigenalis	Red-crowned parrot	1
Anodorhynchus hyacinthinus	Hyacinthine macaw	1
Ara ararauna	Yellow and blue macaw	2
Ara chloroptera	Red and yellow macaw	1
Ara macao	Red, yellow and blue macaw	4
Ara maracana	Illiger's macaw	4
Ara mexicana	Mexican green macaw	3
Ara severa	Severe macaw	1
Aratinga holochlora	White-eyed parrot	1
Aratinga jendaya	Jenday conures	1
Aratinga solstitialis	Yellow paroquet	1
Brotogeris jugularis	Tovi paroquet	2
Coracopsis nigra	Lesser vasa parrot	1
Cyanopsittacus spixi	Spix's macaw	2
Eolophus roseicapillus	Roseate cockatoo	4
Eupsittula aurea	Golden-crowned paroquet	1

Psittacidae—Continued.

Eupsittula canicularis	Petz paroquet	1
Forpus guianensis	Green-rumped parrotlet	1
Kakatoe citrinocristata	Orange-crested cockatoo	1
Kakatoe galerita	Sulphur-crested cockatoo	2
Kakatoe leadbeateri	Leadbeater's cockatoo	2
Kakatoe moluccensis	Great red-crested cockatoo	1
Kakatoe sulphurea	Lesser sulphur-crested cockatoo	1
Leptolophus novaehollandicus	Cockatiel	2
Melopsittacus undulatus	Grass paroquet	20
Microglossus aterrimus	Great black cockatoo	1
Myopsitta monachus	Quaker paroquet	1
Nandayus nanday	Nanday paroquet	1
Nestor notabilis	Kea	4
Pionites xanthomera	Amazonian caique	2
Pionus menstruus	Blue-headed parrot	1
Psittacula k. krameri	Long-tailed paroquet	3
Psittacula nepalensis	Nepalese paroquet	1
Psittacus erithacus	African gray parrot	2
Tanygnathus megalorhynchus	Great-billed parrot	1

CUCULIFORMES

Cuculidae:

Centropus sinensis	Sumatran coucal	1
Cuculus canorus	European cuckoo	1
Eudynamis scolopaccus	Koel	2

STRIGIFORMES

Tytonidae:

Tyto alba pratincola	Barn owl	3

Strigidae:

Bubo virginianus	Great horned owl	5
Otus asio	Screech owl	6
Strix varia	Barred owl	12

CAPRIMULGIFORMES

Caprimulgidae:

Chordeiles minor	Night hawk	1

TROGONIFORMES

Trogonidae:

Priotelus temnurus	Cuban trogon	2

CORACIIFORMES

Alcedinidae:

Dacelo gigas	Kookaburra	2

Momotidae:

Momotus momotus parensis	Motmot	2

Bucerotidae:

Buceros rhinoceros	Rhinoceros hornbill	1
Bucorvus abyssinicus	Abyssinian ground hornbill	2
Dichoceros bicornis	Concave casque hornbill	2

PICIFORMES

Ramphastidae:		
Aulacorhynchus erythrognathus	Venezuelan toucanette	1
Pteroglossus bitorquatus	Two-banded aracari	3
Ramphastos ariel	Ariel toucan	1
Ramphastos toco	Toco touuan	2
Selenidera culik	Guiana toucanette	1

PASSERIFORMES

Cotingidae:		
Chasmorhynchus nudicollis	Naked-throated bell-bird	1
Graculidae:		
Gracula palawanensis	Palawan mynah	2
Gracula religiosa	Southern hill mynah	4
Tyrannidae:		
Pitangus sulphuratus	Kiskadee flycatcher	2
Corvidae:		
Aphelocoma californica woodhousei	Woodhouse's jay	2
Calocitta formosa	Mexican magpie jay	1
Cissa chinensis	Chinese cissa	1
Corvus albus	White-breasted crow	2
Corvus brachyrhynchos	American crow	5
Corvus corax sinuatus	American raven	1
Corvus coronoides	Australian crow	1
Corvus cryptoleucus	White-necked raven	7
Cyanocitta cristata	Blue jay	1
Cyanocorax cyanopogon	White-naped jay	2
Pica nuttalli	Yellow-billed magpie	5
Pica pica hudsonia	American magpie	6
Urocissa occipitalis	Red-billed blue magpie	2
Xanthoura luxuosa guatemalensis	Guatemalan green jay	1
Paradiseidae:		
Paradisea minor	Lesser bird of paradise	1
Seleucides niger	12-wired bird of paradise	2
Timaliidae:		
Pomatorhinus erythrogenys imberbis	Salvadori's scimitar-babbler	1
Pycnonotidae:		
Molpastes haemorrhous	Black-headed bulbul	1
Otocompsa jocosus	Red-eared bulbul	1
Turdidae:		
Mimocichla rubripes	Western red-legged thrush	6
Turdus grayi	Bonaparte's thrush	1
Laniidae:		
Lanius dorsalis	Teita fiscal shrike	2
Sturnidae:		
Cosmopsaris regius	Splendid starling	3
Galeopsar salvadorii	Crested starling	1
Lamprocolius sycobius	Southern glossy starling	1
Coerebidae:		
Cyanerpes cyaneus	Blue honey creeper	1
Icteridae:		
Agelaius assimilis	Cuban red-winged blackbird	3
Agelaius icterocephalus	Yellow-headed marsh bird	1

Icteridae—Continued.		
Amblyrhamphus holosericeus	Red-headed marsh troupial	1
Gymnomystax mexicanus	Giant oriole	1
Icterus giraudi	Giraud's oriole	1
Molothrus ater	Cowbird	1
Psomocolax oryxivora	Rice grackle	1
Xanthocephalus xanthocephalus	Yellow-headed blackbird	4
Thraupidae:		
Spindalis pretrei	Cuban spindalis	3
Tanagra luteicapilla	Yellow-crowned euphonia	1
Thraupis cana	Blue tanager	1
Thraupis palmarum melanoptera	Palm tanager	1
Ploceiidae:		
Amadina fasciata	Cut-throat finch	1
Coliuspasser ardens	Red-necked whydah	4
Diatropura procne	Giant whydah	8
Euplectes capensis	Yellow-shouldered whydah	1
Neochmia phaeton	Crimson or blood finch	1
Padda oryzivora	White Java sparrow	2
Ploceus intermedius	Black-cheeked weaver	20
Ploceus rubiginosus	Chestnut-breasted weaver	8
Poephila acuticauda	Long-tailed finch	9
Poephila gouldiae	Gouldian finch	5
Quelea sanguinirostris intermedia	Southern masked weaver finch	1
Steganopleura bichenovii	Banded finch	5
Steganura paradisea	Paradise whydah	7
Taeniopygia castanotis	Zebra finch	3
Fringillidae:		
Carduelis carduelis	European gold finch	1
Fringilla montifringilla	Brambling finch	1
Melopyrrha nigra	Cuban bullfinch	2
Paroaria cristata	Red-crested or Brazilian cardinal	1
Pheucticus tibialis	Yellow grosbeak	1
Serinus canarius	Canary	8
Sicalis minor	Lesser yellow finch	1
Sporophila aurita	Hick's seed-eater	4
Sporophila gutturalis	Yellow-bellied seed-eater	2
Tiaris canora	Melodius grassquit	2
Tiaris olivacea	Mexican grassquit	15
Volatinia jacarini	Blue-black grassquit	2

Reptiles

LORICATA

Crocodylidae:		
Alligator mississipiensis	Alligator	36
Caiman sclerops	Caiman	3
Crocodylus acutus	American crocodile	1
Crocodylus cataphractus	West African crocodile	1
Crocodylus porosus	Salt water crocodile	1
Osteolaemus tetraspis	Broad-nosed crocodile	1

SQUAMATA

Lacertidae:		
Lacerta muralis	Wall lizard	3
Lacerta viridis	Green lizard	3
Agamidae:		
Physignathus lesueurii	Lesueur's water dragon	2
Iguanidae:		
Anolis carolinensis	False chameleon	12
Anolis equestris	Giant anolis	8
Anolis porcatus	Cuban anolis	2
Conolophus subcristatus	Galapagos iguana	1
Cyclura cornuta	Rhinoceros iguana	1
Leiocephalus cubensis	Cuban curl-tailed lizard	13
Phrynosoma cornutum	Horned lizard	6
Phyrnosoma platyrhinos	Horned lizard	3
Plica plica	Plicated lizard	1
Sceloporus magister	Western spiny lizard	1
Sceloporus torquatus cyanogenys	Scaly lizard	2
Sceloporus undulatus	Fence lizard	8
Gerrhosauridae:		
Gerrhosaurus validus	Robust plated lizard	1
Helodermatidae:		
Heloderma horridum	Mexican beaded lizard	1
Heloderma suspectum	Gila monster	1
Teiidae:		
Cnemidophorus s. sexlineatus	Six-lined lizard	4
Crocodilurus lacertinus	Crocodile lizard	3
Dracaena guianensis	Dragon lizard	1
Tupinambis nigropunctatus	Tegu lizard	2
Scincidae:		
Egernia cunninghami	Cunningham's skink	4
Egernia major	Greater skink	1
Eumeces fasciatus	Red-headed skink	1
Eumeces obsoletus	Brown skink	3
Tiliqua nigrolutea	Mottled lizard	1
Tiliqua scincoides	Blue-tongued lizard	2
Trachysaurus rugosus	Stump-tailed lizard	2
Varanidae:		
Varanus gouldii	Gould's monitor	1
Varanus niloticus	African monitor	1
Zonuridae:		
Zonurus giganteus	Black spiny lizard	1

OPHIDIA

Boidae:		
Boa canina	Green tree boa	3
Constrictor constrictor	Common boa	3
Constrictor mexicana	Mexican boa	1
Epicrates angulifer	Cuban tree boa	3
Epicrates cenchris	Rainbow boa	13
Epicrates subflavus	Jamaica boa	1
Eunectes murinus	Anaconda	3
Tropidophis melanurus	Cuban boa	1

Pythonidae:		
Python molurus	Indian python	1
Python regius	Ball python	1
Python reticulatus	Regal python	4
Colubridae:		
Abastor erythrogrammus	Hoopsnake or rainbow snake	3
Alsophis angulifer	Jubo or culebra	3
Coluber c. constrictor	Black snake	3
Drymarchon corais cooperi	Indigo snake	1
Elaphe guttata	Corn snake	7
Elaphe laeta	Emory's snake	1
Elaphe obsoleta confinis	Southern pilot snake	1
Elaphe o. obsoleta	Pilot snake	9
Elaphe quadrivittata	Chicken snake	6
Elaphe vulpina	Fox snake	1
Farancia abacura	Mud or horn snake	1
Heterodon contortrix	Hog-nosed snake	2
Lampropeltis getulus floridana	Florida king snake	7
Lampropeltis g. getulus	King snake	2
Leimadophis andreae	Jubito or magdalena	2
Liopeltis vernalis	Smooth green snake	1
Masticophis sp	Coachwhip snake	2
Natrix cyclopion	Water snake	13
Natrix sp	Water snake	18
Opheodrys aestivus	Rough-scaled green snake	1
Pituophis melanoleucus	Bull snake	1
Pituophis sayi	Pine snake	1
Thamnophis sauritus	Ribbon snake	3
Thamnophis s. sirtalis	Garter snake	8
Tretanorhinus variabilis	Cuban water snake	1
Elapidae:		
Micrurus fulvius	Coral snake	1
Naja flava	Golden cobra	1
Naja tripudians sumatrana	Sumatran black-hooded cobra	1
Crotalidae:		
Agkistrodon mokasen	Copperhead	6
Agkistrodon piscivorus	Water moccasin	15
Crotalus adamanteus	Diamond-backed rattlesnake	7
Crotalus atrox	Desert rattlesnake	1
Crotalus confluentus	Western rattlesnake	3
Crotalus horridus	Banded rattlesnake	6
Sistrurus catenatus catenatus	Massasauga	2
Sistrurus miliarius	Pigmy rattlesnake	3
Trimeresurus monticola	Mountain pit viper	1
Viperidae:		
Bitis arietans	Puff adder	1
Vipera berus	European viper	2

TESTUDINATA

Chelydidae:		
Hydromedusa tectifera	South American snake-necked turtle	4
Platemys platycephala	Flat-head turtle	1

Pelomedusidae:		
Pelomedusa galeata	Common African water-tortoise	2
Podocnemis expansa	South American river tortoise	1
Kinosternidae:		
Kinosternon flavescens	Musk turtle	1
Kinosternon subrubrum	Musk turtle	4
Chelydridae:		
Chelydra osceola	Osceola snapping turtle	1
Chelydra rossignonii	Rossignon's snapping turtle	1
Chelydra serpentina	Snapping turtle	4
Macrochelys temminckii	Alligator snapping turtle	1
Testudinidae:		
Chrysemys picta	Painted turtle	6
Clemmys guttata	Spotted turtle	1
Clemmys insculpta	Wood tortoise	2
Clemmys muhlenbergii	Muhlenberg's tortoise	1
Cyclemys amboinensis	Malayan box turtle	1
Gopherus agassizii	Agassiz's tortoise	2
Gopherus polyphemus	Gopher tortoise	7
Graptemys pseudogeographica	False geographic turtle	1
Malaclemmys centrata	Diamond-back terrapin	8
Pseudemys concinna	Cooter	5
Pseudemys decussata	Haitian terrapin	1
Pseudemys elegans	Cumberland terrapin	2
Pseudemys floridana	Florida terrapin	2
Pseudemys rugosus	Cuban terrapin	2
Terrapene carolina	Box tortoise	25
Terrapene major	Florida box turtle	2
Terrapene ornata	Ornate tortoise	1
Testudo elephantina	Elephant tortoise	1
Testudo ephippium	Duncan Island tortoise	4
Testudo hoodensis	Hood Island tortoise	3
Testudo radiata	Radiated tortoise	1
Testudo tabulata	South American tortoise	1
Testudo torneri	Soft-shelled land tortoise	9
Testudo vicina	Albemarle Island tortoise	1
Trionychidae:		
Amyda ferox	Soft-shelled turtle	7

AMPHIBIA

CAUDATA

Salamandridae:		
Salamandra salamandra	Salamander	3
Triturus pyrrhogaster	Red-bellied Japanese newt	6
Triturus viridescens	Common newt	18
Amphiumidae:		
Amphiuma means	Blind eel or Congo snake	2
Amphiuma tridactylum	Blind eel or Congo snake	1
Cryptobranchidae:		
Cryptobranchus alleganiensis	Hellbender	3
Necturidae:		
Necturus maculosus	Mud puppy	2

SALIENTIA

Brachycephalidae:		
Atelopus varius cruciger	Yellow atelopus	1
Atelopus varius varius	Yellow atelopus	6
Discoglossidae:		
Bombina bombina	Fire-bellied toad	2
Dendrobatidae:		
Dendrobates auratus	Arrow-poison frog	30
Dendrobates pumilio	Red dendrobates	1
Bufonidae:		
Bufo alvarius	Green toad	5
Bufo americanus	Common American toad	2
Bufo empusus	Sapo de concha	15
Bufo marinus	Marine toad	4
Bufo peltocephalus	Cuban giant toad	10
Ceratophrydae:		
Ceratophrys dorsata	Horned toad	2
Hylidae:		
Acris gryllus	Cricket frog	2
Hyla arborea	Green tree frog	4
Hyla caerulea	Australian tree frog	7
Hyla cinerea	Florida tree frog	1
Hyla crucifer	Tree frog	4
Hyla septentrionalis	Cuban tree frog	17
Pipidae:		
Pipa americana	Surinam toad	1
Xenopus mulleri	Muller's clawed frog	5
Ranidae:		
Rana aesopus	Gopher frog	1
Rana catesbeiana	Bull frog	1
Rana clamitans	Green frog	1
Rana sphenocephala	Southern leopard frog	1

FISHES

Acanthopthalmus kuhlii		5
Barbus sp		8
Betta splendens	Siamese fighting fish	1
Brachydanion rerio	Zebra fish	5
Corydoras aeneus	Trinidad armored catfish	4
Corydoras melanistius	Armored catfish	1
Electrophorus electricus	Electric eel	1
Helostoma temminckii	Kissing gourami	2
Hemigrammus unilineatus		1
Heterandria formosa		8
Hyphessobrycon bifasciatus	Yellow characin	1
Hypostomus sp	Armored catfish	1
Jordanella floridae	American flag fish	7
Kryptopterus bicirrhus	Glass catfish	4
Lebistes reticulatus	Guppy	50
Lepidosiren paradoxa	South American lungfish	3
Leporinus fasciatus		1
Malopterurus electricus	Electric catfish	1
Pantodon buchholzi	Butterfly fish	1

Platypoecilus maculatus	Goldplaties	20
Pristella riddlei		10
Protopterus annectens	African lungfish	2
Pterophyllum scalare	Angel fish	4
Rasbora heteromorpha		3
Trichogaster trichopterus	Three-spot gourami	3
Xiphophorus hellerii	Swordtail	12

ARACHNIDS

Eurypelma sp	Tarantula	5
Latrodectus mactans	Black widow spider	4

INSECTS

Blabera sp	Giant cockroach	50

MOLLUSKS

Achatina variegata	Giant land snail	1

CRUSTACEA

Cardisoma guanhumi	Great land crab	1

Respectfully submitted.

W. M. MANN, *Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1937:

WORK AT WASHINGTON

REVISION OF SOLAR-CONSTANT VALUES

At the beginning of the fiscal year preparations were being made to publish a table of best values of the solar constant of radiation since 1930. This table involved the comparison of results from three field stations, searching for errors of reduction, and examining the records of each individual day for evidences of imperfect observation or unfavorable sky conditions.

But in considering certain discrepancies it suddenly occurred to the Director that a flaw had been overlooked when he devised the so-called short method of reduction in 1923. It will be recalled that in the years 1903 to 1919 all observations of the solar constant had been made by the fundamental or long method. This involved measurements of the intensity of sun rays from early morning until mid-forenoon, and about 2 days of computing to yield one value of the solar constant of radiation. Moreover, if the sky gradually became clearer or more hazy during the several hours of observation, the value obtained would be too high or too low, without any means of recognizing this error.

To save work, to avoid error, and to multiply results, the short method was introduced in 1919. Two solar-constant values could be obtained from observations of only 10 minutes' duration for each, by computations requiring only 1 day for both. In 1923, however, a method occurred to the Director whereby the computing could be almost eliminated, through the use of tables computed once for all. All through the years which have since elapsed this method has been used. Usually, five values were obtained without undue labor for each day observed.

But some months ago, as above stated, the Director perceived that this brief method has a fatal flaw. Without going into technicalities, the defect consists in this: that if the results of two equally clear days are to be compared, on one of which the sun actually emits 1 percent more intense radiation than on the other, the brief method of 1923 will indeed distinguish the day of more intense radiation, but will show less than the true 1 percent change. Moreover, the deficiency of amplitude in solar variation, due to the method of 1923, is greater the more hazy the days, and the lower in altitude the station from which the sun is observed.

Consequently, although the published record of solar variation since 1923 shows solar changes at their right times and in their right directions, the amplitudes of variation found are too small. Also, the hazier stations are at a disadvantage, not only because of their less favorable sky conditions, which naturally give inferior results, but because the method of reduction of 1923 inevitably diminishes the resulting amplitude of the variation of the sun, which they were established to determine, even more than it affects clearer stations.

Our first care was to devise a correct method of reduction, retaining as far as possible the brevity of computation which was the merit of that of 1923. Several months were occupied by the staff at Washington in comparing different proposed methods, checking their results, and at length in computing tables for the one finally selected. This new brief method, although somewhat shorter than the short method used from 1919 to 1923, is far longer than that of 1923. It requires, what was unnecessary for the method of 1923, the complete measurement of the photographic records of observation, just as complete, indeed, as the long method used prior to 1919.

Accordingly, orders were sent to all field stations to have measured, if possible, three bolographs for each day since 1923 when the sun was observed. This heavy task has been to a large degree accomplished by the field observers.

In the meanwhile, by financial aid of John A. Roebling, and by the assistance of W. P. A., the computing staff at Washington has been much enlarged. Great progress has been made in the rereduction of the solar-constant observations. Mount Montezuma observations since 1932 have been fully recomputed, and several years' observations at Table Mountain are done. However, it will require many months before the recomputations are fully completed.

SILVER-DISK PYRHELIOMETERS

As in former years, orders have come from foreign lands for silver-disk pyrheliometers, either new or to be repaired and restandardized. These instruments are in use at nearly a hundred stations in many countries, in all of the continents of the world, to measure the solar radiation. But nowhere are they used in cooperation with the spectroscope, as with us, to make complete determinations of the solar constant of radiation.

ADDITIONAL SOLAR STATIONS

Great hope had been aroused by favorable action of the Senate in June 1936, with approval of the President and the Bureau of the Budget, that as many as seven additional stations for observing the solar constant of radiation could be established. But the hoped-for appropriation having failed in the House, the item was rejected by the Bureau of the Budget in the estimates for 1938, and with the present stress on economy in Government expenditure seems unlikely to be revived. It is still believed that valuable advance in weather forecasting would follow the accurate daily determination of solar variation, such as might be attained with additional solar-constant stations.

LONG-RANGE FORECASTING, LAKE LEVELS, AND TREE RINGS

Letters have been received nearly every day by the Director from drought-stricken areas, some telling of observations confirmatory of his expectations as to the progress of the drought, but most of them begging for predictions to cover ensuing years. The Director, in his replies, has always pointed out the insecurity of such predictions. He has limited himself to referring to indications arising from the history of Great Lakes levels since 1837. These point to a probability that drought conditions in the Northwestern States and neighboring Canada will mend beginning in 1938, but recur in 1975. This view is supported by a record of 400 years' duration in tree rings at Fairlee, Vt., measured by Professor Lyon, of Dartmouth College. Periodicities of 23, 46, and 92 years are plainly apparent therein, which have close relations to the levels of the Great Lakes.

SOLAR ENGINE

The Director caused to be prepared and tested in September 1936 a solar radiation steam boiler of his design. The machine is represented in the accompanying illustration. It exposed 36 square feet (pl. 7) of mirror surface and was intended to produce about ½ horsepower at the engine. Cinematograph records were made of it, and by operating an electric generator a short program was broadcast by solar power. However, the device had many defects, and was not in that form practical for utilizing solar radiation for power. A small solar flash boiler has since been prepared which offers much greater promise.

FIELD WORK

Solar radiation observing stations have been maintained by public funds, supplemented by private resources of the Smithsonian Institution, at Table Mountain, Calif.; Montezuma, Chile; and Mount St. Katherine, Egypt. At these three stations the observations to determine the solar constant of radiation have been made on all favorable days. The average number of days per year suitable for these exacting observations is about the same at these three elevated cloudless desert stations and approaches 80 percent of all days.

PERSONNEL

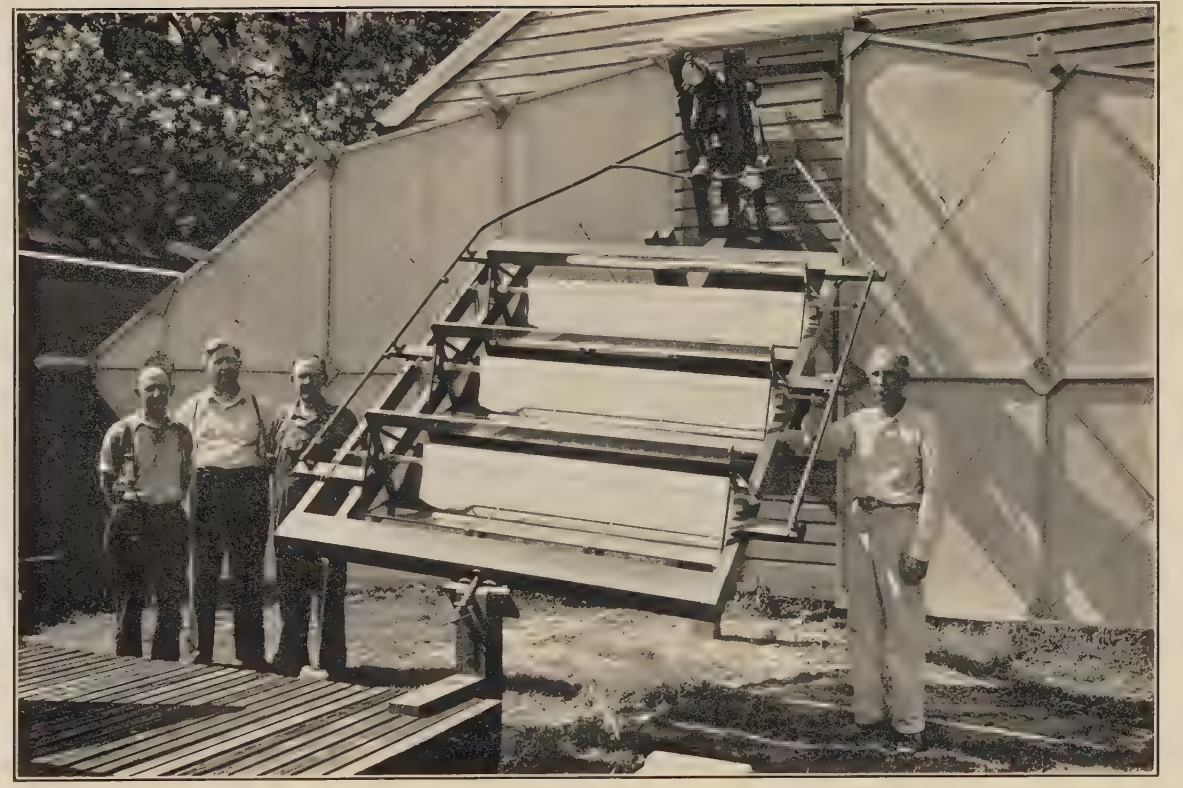
Frederick E. Fowle, research assistant, who joined the staff of the Astrophysical Observatory in the year 1894, was retired for disability at the end of the fiscal year. Mr. Fowle has been associated with practically the entire history of the Observatory, and has taken a large part in its observing, computing, theoretical studies, and plans for its work. He will be especially remembered for his researches on water vapor and ozone in the atmosphere, for his long investigation of the extreme infrared spectrum of water vapor, and for his authorship of numerous editions of "Smithsonian Physical Tables", which enjoy an enviable reputation.

Respectfully submitted.

C. G. Abbot, *Director.*

The Secretary,
Smithsonian Institution.

PLATE 7



THE ABBOT SOLAR RADIATION STEAM BOILER IN THE YARD OF THE ASTROPHYSICAL OBSERVATORY, SEPTEMBER 1936.

APPENDIX 8

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

SIR: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during the year ended June 30, 1937:

Notable successes have been attained during the year in the studies of photosynthesis, of phototropism, and of special reactions of ultraviolet rays in the economy of various plant forms.

W. H. Hoover published the results of several years' study of photosynthesis in wheat. This basic study was made with wheat grown in glass tubes of measured temperature, humidity, and carbon dioxide content, under nearly monochromatic selected spectral rays of measured intensity.[1] Various radiation sources were employed, sometimes the Mazda electric light, sometimes the mercury arc, sometimes the sun. The results are of high accuracy. They give to a probable error of only 2 percent in most spectral regions the dependence on wave length of the assimilation of carbon dioxide by wheat. The accompanying figure shows that photosynthesis in wheat, starting from zero at the end of the visible red, reaches a high maximum in the red at 6500 A, diminishes through the yellow and green, reaches a subordinate maximum in the blue at 4400 A, and then fades away in the violet.

Mr. Hoover's work was accomplished by a chemical method of estimating the air content of carbon dioxide. During the year Dr. McAlister has further perfected a spectral absorption method of extraordinary sensitiveness and extreme rapidity for measuring carbon dioxide concentration in air. The apparatus has been standardized by him and has become a tool which bids fair to be of immense value for the detection and measurement, not only of carbon dioxide, but carbon monoxide, and other organic chemical compounds of extreme interest in plant physiology, human metabolism, mine explorations, and perhaps in other industrial fields. In connection with this apparatus, L. B. Clark has developed an extremely sensitive and rugged thermocouple, the evacuated housing of which is sealed by a bubble window of microscopically thin glass. These beautiful devices together add greatly to the practical success of the spectral absorption method. The new apparatus has been duplicated in our shop for intensive use in photosynthetic studies. We expect to observe photosynthesis quantitatively in various families of plants.

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[1] Smithsonian Misc. Coll., vol. 95, no. 21, pp. 1–13, figs. 1–4, pls. 1–3, 1937.

Dr. McAlister published preliminary results of a research on time relations in photosynthesis. He showed that intermittent illumination gives very different growth rates depending on the rapidity of intermittance. With alternations of light and darkness 60 times per second the growth rate over a period of several hours was actually twice as rapid as with continuous illumination of an equal total quantity of light supplied. Owing to the practically instantaneous character of his measurements, he was able, for the first time, in studies of plant physiology, to turn on the light and continuously follow what happens in plant growth. Many most interesting observations were recorded.[2]

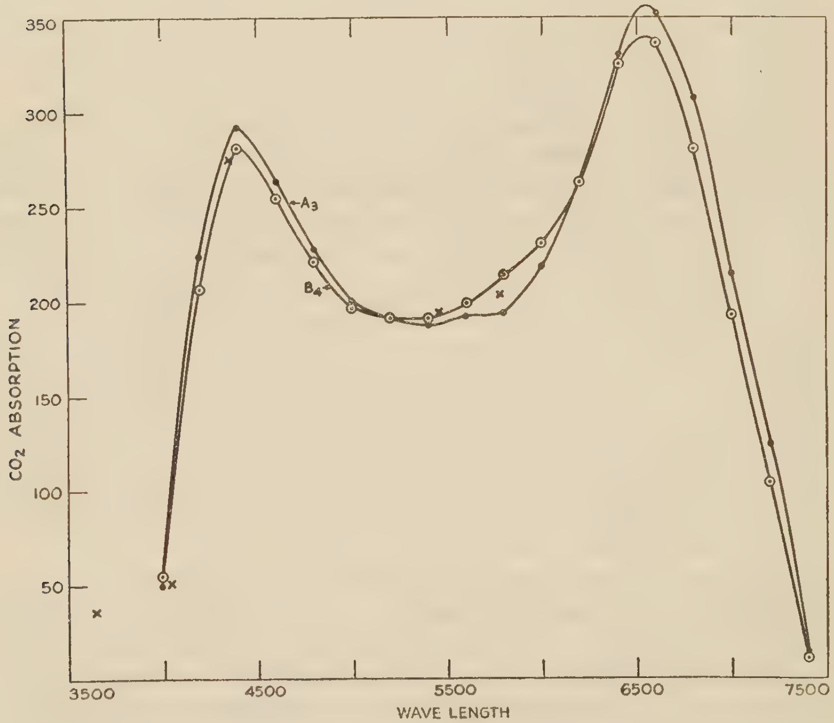

FIGURE 1.—Wave-length assimilation curves.

In a cooperative research with Dr. Flint, of the United States Department of Agriculture, Flint and McAlister examined the efficiency of different wave lengths of light to promote germination in light-sensitive lettuce seed.[3] Their results tie in most suggestively with the curve of chlorophyll absorption. Wave-length regions inhibiting germination were found in the blue and in the infrared spectrum.

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[2] Smithsonian Misc. Coll., vol. 95, no. 24, pp. 1–17, figs. 1–10, pls. 1, 2, 1937.

[3] Smithsonian Misc. Coll., vol. 96, no. 2, pp. 1–8, figs. 1, 2, pl. 1, 1937.

Dr. E. S. Johnston continued with marked progress his investigations tending to produce normal growth of tomato plants under laboratory conditions. The great difficulty is to obtain from artificial sources light of sufficient intensity and proper wave-length distribution. By various ingenious expedients he has to a considerable degree solved the problem.

He also continued phototropic experiments, studying the bending of plants toward the light as well as carbon dioxide assimilation with polarized as compared to normal light. It had been suggested that a real difference would be found, but he found none.

With Dr. P. R. Burkholder, of Connecticut College, Dr. Johnston investigated the inactivation of plant growth substance by light.[4] A very beautiful technique was developed, whereby live tips and half tips of oat seedlings were applied in various ways to decapitated oat seedlings in order to determine what are the circumstances which govern elongation under the influence of light. The results appear to show that under considerable intensities of light the growth hormones are inactivated rather than displaced in producing the well-known lower stature of illuminated plants as compared with plants grown in semidarkness. For further information see their very interesting paper.

Dr. Meier did much work on the classification of a large collection of algae for the National Herbarium. Her own investigations concerned a search for the stimulation of multiplication in algae by ultraviolet rays known to be lethal in doses of sufficient intensity. The research is not finished as yet, but plainly shows great stimulative influence by minute doses of these lethal rays, and that the degree of stimulation is most interestingly connected both with wave length and with the lethal dosage.

The instrument maker, Mr. Fillmen, and the glass technician, Mr. Clark, constructed apparatus of invaluable use in these investigations.

Respectfully submitted.

C. G. Abbot, *Director*.

The Secretary,
Smithsonian Institution.

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[4] Smithsonian Misc. Coll., vol. 95, no. 20, pp. 1–14, fig. 1, pls. 1, 2, 1937.

APPENDIX 9

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1937:

THE LIBRARY

The library, or library system, of the Smithsonian is made up of 45 libraries, all more or less specialized and independent in their nature and location, but all cooperating under the central purpose of the Institution. They are the Smithsonian deposit in the Library of Congress, which is the main unit of the system; the library of the United States National Museum; the library of the Bureau of American Ethnology; the Smithsonian office library; the library of the Astrophysical Observatory; the library of Radiation and Organisms; the library of the Freer Gallery of Art; the library of the National Collection of Fine Arts (until recently the National Gallery of Art); the Langley aeronautical library, since 1930 on special deposit in the Library of Congress; the library of the National Zoological Park; and, finally, the 35 sectional libraries of the National Museum.

PERSONNEL

There were two changes in the permanent staff. Lucile A. Torrey, senior stenographer in the office of the librarian, was appointed to the newly established position of library assistant in the National Collection of Fine Arts, and Mrs. George C. Rodgers was chosen for the vacancy—a position she had formerly held. Carroll M. Martin, assistant messenger in the National Museum library, was transferred to the Social Security Board, and Joseph Salat, Jr., succeeded him.

The temporary assistants were Helen G. Rankin and Margaret Kober. Fifteen workers were also assigned to the library for various periods by the Works Progress Administration.

EXCHANGE OF PUBLICATIONS

The exchange work of the year brought to the library, as usual, a wealth of publications. These represented most of the 22,714 packages received by mail and the 2,226 by the International Exchange Service—a total of 24,940, or an increase of 764 over 1936. Each package contained one or more items. Among the largest sendings were those from the Australian National Research Council, Sydney; Deutsche Chemische Gesellschaft, Berlin; Royal Society of Tasmania, Hobart; Royal Society of Victoria, Melbourne; Société Géologique de Belgique, Liége; Society for the Preservation of the Fauna of the Empire, London; Verein der Freunde der Naturgeschichte in Mecklenburg, Rostock; and Zoological Society of London.

The number of dissertations received was 5,367, or 1,654 fewer than the year before. Of these, 2,292 were sent to the Smithsonian deposit; the other 3,075, being medical in character, were forwarded to the Surgeon General's library. They came from the Academy of Freiberg, the universities of Basel, Berlin, Bern, Bonn, Braunschweig, Breslau, Cornell, Delft, Erlangen, Freiburg, Giessen, Heidelberg, Helsingfors, Jena, Johns Hopkins, Kiel, Königsberg, Leipzig, Liége, Lund, Lwów, Marburg, Neuchâtel, Pennsylvania, Rostock, Strasbourg, Tübingen, Utrecht, Wittenberg, Würzburg, and Zürich, and the technical schools of Berlin, Braunschweig, Dresden, Karlsruhe, and Zürich.

The staff wrote 2,307 letters, most of which had to do with the exchange of publications. They obtained by special correspondence and by search among the Smithsonian duplicates 4,580 volumes and parts needed in various sets, particularly in the Smithsonian deposit and the libraries of the National Museum, Astrophysical Observatory, and National Zoological Park. They also arranged for 262 new exchanges.

It should be noted that, while the number of small sendings received has increased somewhat during recent years, the number of large ones has diminished. This falling off in the large sendings would indicate that the special effort of the employees in the libraries of the Smithsonian, begun sometime ago, to recheck the main sets for missing numbers and obtain by exchange as many of these as possible while they were still available, has been highly successful, at least so far as the gaps, especially the longer ones, can be filled in this manner. It is reasonable to expect, therefore, that most of the substantial sendings in the future will not be to fill out old sets, but rather to supply the library with earlier numbers of comparatively new serials needed in the work of the Institution. For the staff in taking up new exchanges have two aims constantly before them—to serve Smithsonian scientists and to conserve Smithsonian publications. They also, of course, do what they can, in cooperation with the offices of publications, to encourage the return of duplicates not wanted by institutions to which they have been distributed, that these may be used again in the exchange work of the Institution. The success of this cooperative service the past few years has been noteworthy.

GIFTS

There were many gifts during the year. The Philosophical Society of Washington turned over to the library several thousand copies of its Bulletin to be used for exchange purposes. The Geophysical Laboratory presented 838 miscellaneous publications; the American Association for the Advancement of Science, 525; the American Art Association, Anderson Galleries, 38 priced catalogs of art objects; and both the Anthropological Society and the Biological Society of Washington, a substantial number of journals. The outstanding gift, however, was a collection, numbering nearly 4,500, mainly on botany, that had been part of the working library of the late Dr. Frederick V. Coville, chief botanist of the Department of Agriculture and honorary curator of the division of plants in the National Museum. The collection was presented by Mrs. Coville.

Among other important gifts were, Ancient Egyptian Paintings, in three volumes, by Nina M. Davies, with the editorial assistance of Alan H. Gardiner, from John D. Rockefeller, Jr.; Red-Figured Athenian Vases in the Metropolitan Museum of Art, in two volumes, by Gisela M. A. Richter, from the Metropolitan Museum; Catalogue of Hispanic Pottery, by Alice Wilson Frothingham, and Catalogue of Laces and Embroideries, by Florence Lewis May, in the collection of the Hispanic Society of America, from the Society; Index Catalogue of the Library of the Surgeon General's Office, fourth series, volume 1 (two copies), from the Army Medical Library; A Catalogue of the Collection of Martinware Formed by Frederick John Nettlefold, together with a Short History of the Firm of R. W. Martin and Brothers of Southhall, by Charles R. Beard, from Frederick John Nettlefold; Nel Cinquantenario della Società Edison, 1884–1934, in four volumes, edited by Giacinto Motta, from the editor; Gregorio Vázquez de Arce y Ceballoz, by Roberto Pizano Restrepo, from the Government of Colombia; Georg Wilhelm Steller, the Pioneer of Alaskan Natural History, by Leonhard Stejneger, from the author; French Arts and Letters and Other Essays, by W. Francklyn Paris, from the author; An Essex Index, in four volumes, compiled by Fred J. Brand, from the compiler; Bibliography and Index of Geology Exclusive of North America, volume 2, by John M. Nickles and Robert B. Miller, and volume 3, by John M. Nickles, Marie Siegrist, and Eleanor Tatge, from Marie Siegrist; Oceanic Birds of South America, in two volumes, by Robert C. Murphy, from the American Museum of Natural History; The Birds of the Malay Peninsula, volume 3, by Herbert C. Robinson and Frederick N. Chasen, from Gertrude Abbott; Proboscidea, volume 1, by Henry Fairfield Osborn, from the Osborn Library; Fragments of Entomological History, by Herbert Osborn, from the author; Moss Flora of North America North of Mexico, volume 1, part 1, by A. J. Grout, from the author; Praktikum der Edelsteinkunde, by Georg O. Wild, from Alfred N. Goldsmith; and several publications, including J. M. W. Turner, by W. L. Wyllie, and the De Luxe Illustrated Catalogue of Early American Portraits Collected by Thomas B. Clarke, from Theodore Bolton.

Finally, there were gifts from members and associates of the Smithsonian staff, notably Secretary Abbot and Assistant Secretary Wetmore. Mrs. Charles D. Walcott also gave a large number of items, including two copies of her recently published Illustrations of North American Pitcherplants.

SOME STATISTICS

Accessions to the various libraries:

	Volumes	Pamphlets and charts	Total	Approximate holdings June 30, 1937
Astrophysical Observatory	326	95	421	9,197
Bureau of American Ethnology	580	----------	580	51,000
Freer Gallery of Art	629	114	743	12,674
Langley Aeronautical	34	25	59	3,328
National Collection of Fine Arts	402	355	757	5,784
National Museum	2,486	951	3,437	207,142
National Zoological Park	89	10	99	3,571
Radiation and Organisms	4	3	7	245
Smithsonian deposit, Library of Congress	3,037	2,006	5,043	553,078
Smithsonian office	302	21	323	30,503
Total	7,889	3,580	11,469	[1] 876,522

[1] These holdings do not, of course, include the thousands of volumes still unbound, uncataloged, or incomplete.

The number of periodicals entered was 24,212; of publications cataloged, 6,766; of cards prepared and filed, 28,967; of loans made, 10,995, of which 196 were to libraries outside the Institution and its branches. From the Library of Congress 1,942 publications were borrowed, and from other libraries, 386.

The index of Smithsonian publications was kept up to date; the index of exchange relations was advanced; and the union catalog received considerable attention, as the following table will show:

Volumes cataloged	4,122
Pamphlets and charts cataloged	2,427
New serial entries made	218
Typed cards added to catalog and shelf list	4,733
Library of Congress cards added to catalog and shelf list	2,239

BINDING

More time than usual was spent by the staff in preparing periodicals for binding, with the following results: the library of the National Museum sent to the bindery 1,846 volumes; the library of the Bureau of American Ethnology, 1,330; the Smithsonian office library, 271; the library of the Astrophysical Observatory, 189; the library of the National Collection of Fine Arts, 113; and the library of the Freer Gallery of Art, 54. The binding of these 3,803 volumes—or all but 106 of them, which were otherwise provided for—was made possible by the deficiency appropriation of $12,000 approved toward the close of 1935. Mention should also be made of the fact that an experienced binder, assigned to the National Zoological Park under the W. P. A., bound 389 volumes for the library of the Park and several other libraries of the Smithsonian; and of the further fact that this expert and two other W. P. A. workers repaired about 500 books, thus extending their period of usefulness.

OTHER ACTIVITIES

Special attention was given during the year to the libraries of the National Collection of Fine Arts and the National Zoological Park. As a consequence, much progress was made in sorting their accumulations of miscellaneous material and rendering the publications retained available for use. Many items needed in the files were supplied by the Library of Congress, National Museum, and Smithsonian Institution.

The work of the 15 W. P. A. employees assigned to the library consisted largely of typing letters, copying cards, repairing books, putting pamphlets into binders and labeling them appropriately, preparing, mounting, and filing aeronautical clippings, checking and sorting publications, shelving duplicates, recording periodicals, and assisting with the cataloging.

Smithsonian duplicates were sent, on special exchange, to the Bureau of Mines, Ecuador, and the following colleges and universities: Brown, Columbia, Franklin and Marshall, Harvard, Pennsylvania, Princeton, Rollins, and Yale.

Steps were taken late in the year to provide a third lot of steel shelving for the technological library. When this is installed, it will increase materially the shelf space for this important collection and make possible, it is hoped, the early completion of the reorganization of the libraries in the Arts and Industries Building begun some years ago.

The reference and bibliographical work of the various libraries of the Institution, which has steadily increased since 1924, reached in 1937 a high point of effectiveness, requiring much time from several members of the staff and involving service, not only to the scientists and associates of the Smithsonian and to other Government employees, but to many inquirers outside of Washington.

NEEDS

The library needs a larger annual allotment for binding, so that this essential activity may be brought and kept up to date. There should also be an increase in the funds available for purchasing publications that have a direct bearing on the projects, both present and prospective, of the scientific staff and cannot be found in Washington or obtained by exchange. Two other needs should be considered in due time: more trained catalogers to correct and revise the catalog of the National Museum library and more shelf room for its collections.

Respectfully submitted.

William L. Corbin, *Librarian.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government branches under its administrative charge during the year ended June 30, 1937:

The Institution published during the year 16 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report, and pamphlet copies of the 27 articles contained in the report appendix, and 2 special publications.

The United States National Museum issued 1 annual report, 2 bulletins, and 29 Proceedings papers.

The Bureau of American Ethnology issued 1 annual report and 1 bulletin.

Of the publications there were distributed 144,817 copies, which included 70 volumes and separates of the Smithsonian Contributions to Knowledge, 34,178 volumes and separates of the Smithsonian Miscellaneous Collections, 23,906 volumes and separates of the Smithsonian Annual Reports, 2,220 Smithsonian special publications, 68,822 volumes and separates of the National Museum publications, 14,708 publications of the Bureau of American Ethnology, 90 publications of the National Gallery of Art, 110 publications of the Freer Gallery of Art, 24 annals of the Astrophysical Observatory, 16 reports of the Harriman Alaska Expedition, and 673 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 73, there was issued 1 paper; volume 91, 2 papers; volume 95, 12 papers and title page and table of contents; and volume 96, 1 paper, making 16 papers in all, as follows:

VOLUME 73

No. 8. Opinions rendered by the International Commission on Zoological Nomenclature. Opinions 124 to 133. 44 pp. (Publ. 3395.) October 28, 1936.

VOLUME 91

Reports on the collections obtained by the first Johnson-Smithsonian Deep-Sea Expedition to the Puerto Rican Deep.

No. 25. A new Actinian, by Oskar Carlgren. 4 pp., 3 figs. (Publ. 3401.) January 30, 1937.

No. 26. New species of mysidacid crustaceans, by Walter M. Tattersall. 18 pp., 10 figs. (Publ. 3413.) May 7, 1937.

VOLUME 95

No. 13. A comparative study of the labium of coleopterous larvae, by W. H. Anderson. 29 pp., 8 pls. (Publ. 3393.) August 11, 1936.

No. 14. Morphology of the insect abdomen. Part III. The male genitalia (including arthropods other than insects), by R. E. Snodgrass. 96 pp., 29 figs. (Publ. 3396.) October 12, 1936.

No. 15. Further evidence on the dependence of terrestrial temperatures on the variations of solar radiation, by C. G. Abbot. 4 pp., 2 figs. (Publ. 3397.) August 12, 1936.

No. 16. A seventeenth century letter of Gabriel Diaz Vara Calderón, Bishop of Cuba, describing the Indians and Indian missions of Florida, by Lucy L. Wenhold. 14 pp., 12 pls. (Publ. 3398.) November 20, 1936.

No. 17. A new race of the song sparrow from the Appalachian region, by Alexander Wetmore. 3 pp. (Publ. 3399.) September 26, 1936.

No. 18. Two original photographic negatives of Abraham Lincoln, by Alexander Wetmore. 2 pp., 4 pls. (Publ. 3400.) October 16, 1936.

No. 19. Cycles in tree-ring widths, by C. G. Abbot. 5 pp., 1 fig. (Publ. 3402.) December 16, 1936.

No. 20. Inactivation of plant growth substance by light, by Paul R. Burkholder and Earl S. Johnston. 14 pp., 2 pls., 1 fig. (Publ. 3403.) February 5, 1937.

No. 21. The dependence of carbon dioxide assimilation in a higher plant on wave length of radiation, by W. H. Hoover. 13 pp., 3 pls., 4 figs. (Publ. 3406.) February 27, 1937.

No. 22. Third contribution to nomenclature of Cambrian trilobites, by Charles Elmer Resser. 29 pp. (Publ. 3408.) April 5, 1937.

No. 23. On the corrections to be applied to silver-disk pyrheliometry, by C. G. Abbot. 7 pp. (Publ. 3409.) March 10, 1937.

No. 24. Time course of photosynthesis for a higher plant, by E. D. McAlister. 17 pp., 2 pls., 10 figs. (Publ. 3410.) May 4, 1937.

Title page and table of contents. (Publ. 3415.)

VOLUME 96

No. 2. Wave lengths of radiation in the visible spectrum promoting the germination of light-sensitive lettuce seed, by Lewis H. Flint and E. D. McAlister. 8 pp., 1 pl., 2 figs. (Publ. 3414.) June 16, 1937.

SMITHSONIAN ANNUAL REPORTS

Report for 1935.—The complete volume of the Annual Report of the Board of Regents for 1935 was received from the Public Printer in October 1936.

Annual Report of the Board of Regents of the Smithsonian Institution showing operations, expenditures, and condition of the Institution for the year ending June 30, 1935. xiv+580 pp., 95 pls., 89 text figs. (Publ. 3348.)

The appendix contained the following papers:

Weather governed by changes in the sun's radiation, by C. G. Abbot.

Seasonal weather and its prediction, by Sir Gilbert T. Walker.

The sun's place among the stars, by Walter S. Adams.

The atmospheres of the planets, by Henry Norris Russell.

The surface features of the moon, by F. E. Wright.

The upper atmosphere, by G. M. B. Dobson, D. Sc., F. R. S.

The nature of the cosmic radiation, by Thomas H. Johnson.

What is electricity? by Paul R. Heyl.

New facts about the nucleus of the atom, by Carl D. Anderson.

The approach to the absolute zero of temperature, by F. Simon, D. Phil.

Discovery and significance of vitamins, by Sir Frederick Gowland Hopkins, P. R. S.

The salinity of irrigation water, by Carl S. Scofield.

Selenium absorption by plants and their resulting toxicity to animals, by Annie M. Hurd-Karrer.

The glacial history of an extinct volcano, Crater Lake National Park, by Wallace W. Atwood, Jr.

Concretions—freaks in stone, by R. S. Bassler.

Biology and human trends, by Raymond Pearl.

The relation of genetics to physiology and medicine, by Thomas Hunt Morgan.

Conservation of the Pacific halibut, an international experiment, by William F. Thompson.

The swallowtail butterflies, by Austin H. Clark.

Those ubiquitous plants called algae, by Florence E. Meier.

The Boulder Canyon project, by Wesley R. Nelson.

Wings over the sea, by Louis Blériot.

The coming of man from Asia in the light of recent discoveries, by Aleš Hrdlička.

The antiquity of man in America in the light of archeology, by N. C. Nelson.

A survey of southwestern archeology, by Frank H. H. Roberts, Jr.

Nuzi and the Hurrians: The excavations at Nuzi (Kirkuk, Iraq) and their contribution to our knowledge of the history of the Hurrians, by Robert H. Pfeiffer.

The ruins of Tenampua, Honduras, by Dorothy H. Popenoe.

Report for 1936.—The report of the Secretary, which included the financial report of the executive committee of the Board of Regents, and will form part of the annual report of the Board of Regents to Congress, was issued in January 1937.

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ending June 30, 1936. 107 pp., 2 pls. (Publ. 3404.)

The report volume, containing the general appendix, was in press at the close of the year.

SPECIAL PUBLICATIONS

Explorations and field work of the Smithsonian Institution in 1936. 100 pp., 98 figs. (Publ. 3407.) April 6, 1937.

Statement to the Smithsonian Board of Regents on 10 years of Smithsonian affairs, by Secretary C. G. Abbot. 10 pp. (Publ. 3412.) April 1937.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 annual report, 2 bulletins, 1 volume of the Proceedings, and 29 separates from Proceedings volumes 83 and 84, as follows:

MUSEUM REPORT

Report on the progress and condition of the United States National Museum for the year ended June 30, 1936. 8vo, iii+115 pp., January 14, 1937.

PROCEEDINGS: VOLUME 83

Complete volume:

Proceedings of the United States National Museum. Vol. 83, 8vo, viii+617 pp., 37 pls., 71 figs.

Separates:

No. 2990. A revision of the chalcid flies of the genus *Perilampus* Latreille occurring in America north of Mexico. By M. T. Smulyan. Pp. 369–412. October 16, 1936.

No. 2991. Pycnogonids from Puget Sound. By Harriet I. Exline. Pp. 413–422, fig. 33. July 9, 1936.

No. 2992. California Crustacea of the order Cumacea. By Carl Zimmer. Pp. 423–439, figs. 34–39. August 27, 1936.

No. 2993. A comparison of the shallow-water sponges near the Pacific end of the Panama Canal with those at the Caribbean end. By M. W. deLaubenfels. Pp. 441–466, figs. 40–45, July 31, 1936.

No. 2994. New species of polychaetous annelids of the family Nereidae from California. By Olga Hartman. Pp. 467–480, figs. 46–53. July 11, 1936.

No. 2995. Four new species of Chalcidoidea parasitic on cactus insects. By A. B. Gahan. Pp. 481–486. August 7, 1936.

No. 2996. The Tertiary Foraminifera of the genera *Operculina* and *Operculinoides* from North America and the West Indies. By T. Wayland Vaughan and W. S. Cole. Pp. 487–496, pls. 35–38. October 8, 1936.

No. 2997. Review of the seahorses (*Hippocampus*) found on the coasts of the American continents and of Europe. By Isaac Ginsburg. Pp. 497–594, figs. 54–71. January 18, 1937.

—— Title page, table of contents, and index. Pp. i–viii, 595–617. March 17, 1937.

VOLUME 84

Separates:

No. 2998. Report on the fishes collected by H. C. Raven in Lake Tanganyika in 1920. By George S. Myers. Pp. 1–15, pl. 1. September 24, 1936.

No. 2999. The ichneumon-flies of the genus *Brachycyrtus* Kriechbaumer. By R. A. Cushman. Pp. 17–24, figs. 1–4. September 26, 1936.

No. 3000. New cottid fishes from Japan and Bering Sea. By Rolf L. Bolin. Pp. 25–38, figs. 5–8. October 10, 1936.

No. 3001. Revision of North American beetles of the staphylinid subfamily Tachyporinae—Part I: Genus *Tachyporus* Gravenhorst. By Richard E. Blackwelder. Pp. 39–54. November 17, 1936.

No. 3002. Revision of the fishes of the family Microdesmidae, with descriptions of a new species. By Earl D. Reid. Pp. 55–72, pl. 2, figs. 9–12. December 10, 1936.

No. 3003. Two new species of hawks from the Miocene of Nebraska. By Alexander Wetmore. Pp. 73–78, figs. 13, 14. November 3, 1936.

No. 3004. A new North American mason-wasp from Virginia, with notes on allied forms. By Joseph Bequaert. Pp. 79–87, fig. 15. November 24, 1936.

No. 3005. The nest of *Odynerus tempiferus* var. *macio Bequaert*, with notes on the habits of the wasps. By Austin H. Clark and Grace A. Sandhouse. Pp. 89–95. November 24, 1936.

No. 3006. Crested millipeds of the family Lysiopetalidae in North America, with descriptions of new genera and species. By H. F. Loomis. Pp. 97–135, pls. 3, 4, figs. 16–18. May 15, 1937.

No. 3007. Notes on phallostethid fishes. By George S. Myers. Pp. 137–143. January 6, 1937.

No. 3008. The deep-sea zeomorph fishes of the family Grammicolepidae. By George S. Myers. Pp. 145–156, pls. 5–7. January 18, 1937.

No. 3009. New North American species of earthworms of the family Megascolecidae. By Frank Smith. Pp. 157–181. January 8, 1937.

No. 3010. Observations on the trematode genus *Brachycoelium* Dujardin. By Elon E. Byrd. Pp. 183–199, pls. 8, 9. April 7, 1937.

No. 3011. New muscoid flies (Diptera) in the United States National Museum. By David G. Hall. Pp. 201–216, figs. 19–26. April 6, 1937.

No. 3012. The pupa of *Myocera tabanivora* Hall (Diptera). By Charles T. Greene. Pp. 217–218, fig. 27. April 6, 1937.

No. 3013. A new subspecies of the nymphalid butterfly *Polygonia faunus*. By Austin H. Clark. Pp. 219–222, pl. 10. April 9, 1937.

No. 3014. A new species of trematode from the mud-eel (*Siren lacertina*). By C. Courson Zeliff. Pp. 223–226, pl. 11. May 4, 1937.

No. 3015. Mexican fossil Echini. By Robert Tracy Jackson. Pp. 227–237, pls. 12–15. June 12, 1937.

No. 3016. Two new beetles of the family Mordellidae from orchids. By Eugene Ray. Pp. 239–241. April 21, 1937.

No. 3018. A revision of the clapper rails (*Rallus longirostris* Boddaert). By Harry C. Oberholser. Pp. 313–354. June 30, 1937.

No. 3020. Synopsis of the Puerto Rican beetles of the genus *Mordellistena*, with descriptions of new species. By Eugene Ray. Pp. 389–399, fig. 28. June 26, 1937.

BULLETINS

No. 153, part 2. Birds collected by the Childs Frick expedition to Ethiopia and Kenya Colony: Passeres. By Herbert Friedmann. xii+506 pp., 14 pls., 30 figs. (colored frontispiece). June 25, 1937.

No. 167. Life histories of North American birds of prey. Part 1: Order Falconiformes. By Arthur Cleveland Bent. viii+409 pp., 102 pls. May 3, 1937.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the bureau has continued under the immediate direction of the editor, Stanley Searles. During the year one annual report and one bulletin were issued, as follows:

Fifty-third Annual Report on the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1935–36. 8 pp.

Bulletin 114. Fox miscellany. By Truman Michelson. 124 pp., 9 figs.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

Volume I of the report for 1935 and volume III of the report for 1931 (Writings on American History, 1932) were issued during the year. The annual report for 1936, volume I, and Writings on American History, 1933 and 1934, were in press at the close of the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Thirty-ninth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, December 3, 1936.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian Annual Reports to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1938, totals $65,000, allotted as follows:

Smithsonian Institution	$12, 500
National Museum	30, 000
Bureau of American Ethnology	13, 300
International Exchange Service	200
National Zoological Park	200
Astrophysical Observatory	400
American Historical Association	8, 000
National Collection of Fine Arts	400

Respectfully submitted.

W. P. TRUE, *Editor.*

DR. C. G. ABBOT,
Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1937

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8s 6d—$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015, which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of	$550, 000. 00
Since the original bequest the Institution has received gifts from various sources chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution. To these gifts has been added capital from savings on income, gain from sale of securities, etc., bringing the total endowment for general purposes to the amount of	1, 132, 868. 57

The Institution holds also a number of endowment gifts, the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Arthur, James, fund, income for investigations and study of sun and lecture on the sun	$39, 993. 48
Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States	50, 101. 00
Baird, Lucy H., fund, for creating a memorial to Secretary Baird	13, 489. 06
Barstow, Frederic D., fund, for purchase of animals for the Zoological Park	760. 67
Canfield Collection fund, for increase and care of the Canfield collection of minerals	38, 247. 22
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera	7, 728. 33
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks	28, 160. 59
Hillyer, Virgil, fund, for increase and care of Virgil Hillyer collection of lighting objects	6, 572. 25
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air	100, 000. 00

Special Research fund, gift, in form of real estate	$20,946.00
Hughes, Bruce, fund, to found Hughes alcove	15,150.12
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of, and benefit of, the National Gallery of Art	18,956.10
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection	2,413.55
Poore, Lucy T., and George W., fund, for general use of the Institution when principal amounts to the sum of $250,000	67,717.14
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis	29,084.86
Roebling fund, for care, improvement, and increase of Roebling collection of minerals	120,682.75
Rollins, Miriam and William, fund for investigations in physics and chemistry	52,902.67
Springer, Frank, fund, for care, etc., of Springer collection and library	17,932.90
Walcott, Charles D., and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof	10,736.20
Younger, Helen Walcott, fund, held in trust	50,112.50
Zerbee, Frances Brincklé, fund, for endowment of aquaria	761.08
Total endowment for specific purposes other than Freer endowment	692,448.47

The capital funds of the Institution, except the Freer funds, are invested as follows:

Fund	United States Treasury	Consolidated fund	Separate fund	Total
Arthur, James		$39,993.48		$39,993.48
Bacon, Virginia Purdy		50,101.00		50,101.00
Baird, Lucy H		13,489.06		13,489.06
Barstow, Frederic D		760.67		760.67
Canfield Collection		38,247.22		38,247.22
Casey, Thomas L		7,728.33		7,728.33
Chamberlain		28,160.59		28,160.59
Hillyer, Virgil		6,572.25		6,572.25
Hodgkins, specific	$100,000			100,000.00
Special Research			$20,946.00	20,946.00
Hughes, Bruce		15,150.12		15,150.12
Myer, Catherine W		18,956.10		18,956.10
Pell, Cornelia Livingston		2,413.55		2,413.55
Poore, Lucy T., and George W	26,670	41,047.14		67,717.14
Reid, Addison T	11,000	13,584.86	4,500.00	29,084.86
Roebling Collection		120,682.75		120,682.75
Rollins, Miriam and William		43,402.67	9,500.00	52,902.67
Smithsonian unrestricted:				
Special			1,400.00	1,400.00
Avery	14,000	37,236.81		51,236.81
Endowment		193,460.03		193,460.03
Habel	500			500.00
Hachenberg		4,021.50		4,021.50
Hamilton	2,500	403.68		2,903.68
Henry		1,209.42		1,209.42
Hodgkins (general)	116,000	30,223.12		146,223.12
Parent	727,640	1,220.78		728,860.78
Rhees	590	473.07		1,063.07
Sanford	1,100	890.16		1,990.16
Springer		17,932.90		17,932.90
Walcott, Charles D., and Mary Vaux		10,736.20		10,736.20
Younger, Helen Walcott			50,112.50	50,112.50
Zerbee, Frances Brincklé		761.08		761.08
Total	1,000,000	738,858.54	86,458.50	1,825,317.04

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally, in his will, probated November 6, 1919, he provided stock and securities to the estimated value of $1,958,591.42 as an endowment fund for the operation of the gallery. From the above date to the present time these funds have been increased by stock dividends, savings of income, etc., to a total of $4,881,986.96. In view of the importance and special nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$546, 932. 11
Court and grounds maintenance fund	137, 506. 17
Curator fund	556, 567. 59
Residuary legacy	3, 640, 981. 09
Total	4, 881, 986. 96

SUMMARY

Invested endowment for general purposes	$1, 132, 868. 57
Invested endowment for specific purposes other than Freer endowment	692, 448. 47
Total invested endowment other than Freer endowment	1, 825, 317. 04
Freer invested endowment for specific purposes	4, 881, 986. 96
Total invested endowment for all purposes	6, 707, 304. 00

CLASSIFICATION OF INVESTMENTS

Deposited in the U. S. Treasury at 6 percent per annum, as authorized in the United States Revised Statutes, sec. 5591		$1, 000, 000. 00
Investments other than Freer endowment (cost or market value at date acquired):		
Bonds (19 different groups)	$300, 367. 31	
Stocks (41 different groups)	474, 721. 18	
Real estate and first-mortgage notes	41, 746. 00	
Uninvested capital	8, 482. 55	
		825, 317. 04
Total investments other than Freer endowment		1, 825, 317. 04

Investments of Freer endowment (cost or market value at date acquired):		
Bonds (44 different groups)	$2,379,555.93	
Stocks (54 different groups)	2,449,697.40	
Real estate first-mortgage notes	24,500.00	
Uninvested capital	28,233.63	
		$4,881,986.96
Total investments		6,707,304.00

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR [1]

Cash balance on hand June 30, 1936		$222,452.43
Receipts:		
Cash income from various sources for general work of the Institution	$72,439.29	
Cash gifts and contributions expendable for special scientific objects (not to be invested)	33,440.45	
Cash gifts for special scientific work (to be invested)	105.00	
Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances)	64,517.29	
Cash received as royalties from Smithsonian Scientific Series	40,793.33	
Cash capital from sale, call of securities, etc. (to be reinvested)	52,674.65	
Total receipts other than Freer endowment		263,970.01
Cash receipts from Freer endowment, income from investments, etc	$280,969.53	
Cash capital from sale, call of securities, etc. (to be reinvested)	754,715.98	
Total receipts from Freer endowment		1,035,685.51
Total		1,522,107.95
Disbursements:		
From funds for general work of the Institution:		
Buildings, care, repairs, and alterations	$4,717.66	
Furniture and fixtures	570.51	
General administration [2]	28,464.76	
Library	2,101.26	
Publications (comprising preparation, printing, and distribution)	14,639.95	
Researches and explorations	27,254.20	
International Exchanges	3,263.08	
		81,011.42

[1] This statement does not include Government appropriations under the administrative charge of the Institution.

[2] This includes salary of the Secretary and certain others.

Disbursements—Continued.		
From funds for specific use, other than Freer endowment:		
Investments made from gifts, from gain from sale, etc., of securities and from savings on income	$26,168.15	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances)	78,947.71	
Reinvestment of cash capital from sale, call of securities, etc	44,383.42	
Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased	2,079.24	
		$151,578.52
From Freer endowment:		
Operating expenses of the gallery, salaries, field expenses, etc	49,422.18	
Purchase of art objects	141,942.96	
Investments made from gain from sale, etc., of securities	230,665.78	
Reinvestment of cash capital from sale, call of securities, etc	490,327.70	
Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased	22,864.69	
		935,223.31
Cash balance June 30, 1937		354,294.70
Total		1,522,107.95

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, PUBLICATIONS, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general funds of the Institution:		
Publications	$17,090.34	
Researches and explorations	27,254.20	
		$44,344.54
Expenditures from funds devoted to specific purposes:		
Researches and explorations	49,757.28	
Care, increase, and study of special collections	10,787.39	
Publications	5,606.02	
		66,150.69
Total		110,495.23

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to $1,249.26.

The Institution gratefully acknowledges gifts or bequests from the following:

Dr. William L. Abbott, portion of bequest left to the Smithsonian Institution.

Friends of Dr. Albert S. Hitchcock, for establishment and care of a library in his name.

Edith C. Long, bequest for care of collection of laces, etc., presented to the Institution.

Mr. John A. Roebling, further contributions for researches in radiation.

Mrs. Mary Vaux Walcott, for certain publications and purchase of specimens.

Research Corporation, further contributions for researches in radiation.

The Garden Club of America, the Amateur Gardener's Club of Baltimore, the Herb Society of America, and others, for the publishing of the Badianus Manuscript.

All payments are made by check, signed by the Secretary of the Institution on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The foregoing report relates only to the private funds of the Institution.

The following annual appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1937:

Salaries and expenses		$36,330
International Exchanges		44,260
American Ethnology		58,730
Astrophysical Observatory		30,850
National Museum:		
Maintenance and operation	$134,390	
Preservation of collections	604,580	
		738,970
National Gallery of Art[1]		34,275
Printing and binding		55,500
National Zoological Park		225,000
Total		1,223,915

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[1] Name changed to National Collection of Fine Arts by Public Res. 14, 75th Cong., 1st sess., approved Mar. 24, 1937.

The expositions at Cleveland, Ohio, and Dallas, Tex., were continued from last year and the following allotments made for participation therein by the Smithsonian Institution:

Great Lakes Exposition, 1937 and 1938	$350
Greater Texas and Pan American Exposition	5,000

An allotment of $500 was also made to enable the Smithsonian Institution to place an exhibit in the International Exposition held in Paris, France.

The report of the audit of the Smithsonian private funds is printed below:

AUGUST 27, 1937.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1937, and certify the balance of cash on hand, including petty cash fund, June 30, 1937, to be $356,194.70.

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1937, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1937.

Respectfully submitted.

WILLIAM L. YAEGER & CO.,
WILLIAM L. YAEGER,
Certified Public Accountant.

Respectfully submitted.

FREDERIC A. DELANO,
R. WALTON MOORE,
JOHN C. MERRIAM,
Executive Committee.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1937

ADVERTISEMENT

The object of the General Appendix to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1937.

CONSTITUTION OF THE STARS[1]

By Sir ARTHUR STANLEY EDDINGTON
Professor of Astronomy, University of Cambridge

When we turn a telescope on the sun, we look at it through its tenuous envelopes—the corona and chromosphere—then down through a few hundred kilometers of its outermost atmosphere, to a level where it becomes too opaque for us to see further; just as, in looking down on the ocean, we can see down a few feet but no further. At the vaguely defined level which is the limit of our vision, the temperature is about 6,000°. What lies below that level? What is it like deep down in the interior of the sun—and the other stars?

The exploration of the deep interior of the stars began in 1869 with a paper by Homer Lane of Washington, which he entitled, "On the Theoretical Temperature of the Sun, Under the Hypothesis of a Gaseous Mass, Maintaining Its Volume by Its Internal Heat and Depending on the Laws of Physics as Known to Terrestrial Experiment." Evidently he didn't believe in snappy headlines. This paper has been the foundation of developments by Ritter, Emden, and others, which are being continued at the present day.

There is a phrase in the title of Lane's paper which I would underline: "*Depending on the laws of physics as known to terrestrial experiment.*" That expresses the principle of which I profess myself a devotee. We want to find out how far the phenomena which we observe in the sky agree with, and are a consequence of, the laws that have been assigned to matter as the result of terrestrial experiment. Take ordinary matter—some mixture of the elements that we know—and apply on a large scale the properties of matter and radiation that have been found by experiments on a small scale. Treat it as though you were designing a large dam instead of a large star—with just the same kind of calculations and exercising so far as possible the same kind of foresight. The conditions in the star are very extreme; but the ultimate things to be dealt with—electrons, atomic nuclei, X-rays—are the same in the star as in the laboratory, and we can apply our laboratory knowledge of them. Calculate in this way what will be the properties of the huge mass—what, for example, will be its output of heat and light, what will be its period if it is set pulsating. Calculate "according to the laws of physics as known to terrestrial experiment"; and then turn to the man with the telescope and ask, "Is that anything like the stars *you* come across in the sky?" It may be that he will point out differences. If the stars have anything new to reveal to us—which the physicist with his limited conditions of experiment has been unable to foresee—we shall in this way sort it out from that which is a direct consequence of what we already know or think we know.

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[1] Address given at the Harvard Tercentenary Conference of Arts and Sciences. Published by permission of the Director of the Harvard Tercentenary.

Investigations which follow this course of procedure are clearly not speculative. They may have other faults, and their conclusions may be uncertain; but their method is the very opposite to flighty conjecture. Parenthetically, may I ask whether it is not possible for critics of theoretical investigations of the stars to find some other term of disapprobation than the term "speculative"; one prefers to have even one's faults called by the right name. I do not class all speculation as a fault; and it has sometimes happened that important advances have begun in a speculative way. The real harm is when speculative attempts are not sufficiently discriminated from the straightforward application of existing knowledge. And the converse is no less harmful—when Lane's pattern of investigation, that is to say, the results of applying on the stellar scale the laws found in the laboratory, is confused with the frankly speculative theories that have at times been put forward; and (perhaps I may add for the benefit of the mathematicians here) worst of all, when stars constituted of matter obeying the laws of physics so far as they have been unraveled to-day, are confused with mathematical creations whose only claim on our attention is that they satisfy elegant differential equations.

I will not guarantee that the conclusions that I shall put before you will survive the progress of knowledge in the next 50 years. If by then the stars of gaseous constitution which we accept today have given place to liquid stars or solid stars or, as I once suggested, crystalline stars composed of *gaseous* crystals—well, there have been more surprising changes in science than that. But I believe firmly that the conclusions are such as fit our present scientific knowledge; and that they represent present-day astronomy in step with present-day physics. To use a rather favorite word nowadays, *unification*, the interest of these investigations is, I think, not so much dependent on the absolute information they yield, as in the unification of physics and astrophysics—enabling us to see one underlying cause or one elementary equation at the root of the most diverse manifestations, tracing its effects in the vacuum tube, in the interior of stars, in the diffuse nebulae, and—not least—in the system of galaxies which constitutes the cosmos.

I want to leave time to speak of recent problems, so I will run over rather briefly the older part of the subject. Let us suppose that by observation from outside we have ascertained the mass M and the radius R of a star—just those two data. Armed with this information, what can we deduce (by laws of physics) about its interior?

The first difficulty is that, although we have ascertained the total mass, we have not found how it is distributed—whether it is fairly uniform throughout the volume of the star or strongly concentrated to the center. I will not stop to explain how we have got over this difficulty; but it is a side of the problem in which considerable progress has been made in the last year or two. Although we cannot determine the concentration accurately, we can assign limits by purely theoretical deduction. The central density is not less than 5 times the mean density, and not more than 50 times the mean density—so that we know roughly the degree of concentration that we are up against.

Knowing then how the mass is distributed in the structure we can calculate the pressure at any depth. Any civil engineer will tell you that that is possible; so that we know the pressure as well as the density at each point in the interior. Now the density, pressure, and temperature are connected by a relation called the *equation of state* of the material; if any two of them are known we can find the third. In this case we know the pressure and density and we can therefore find the temperature—which is, of course, an extremely important thing to find out, in order to realize the sort of conditions we have to deal with. For all the stars except white dwarfs, the equation of state, which connects the temperature with the pressure and density, is the well-known equation of a perfect gas. For the extremely dense matter in white dwarf stars the equation is more complicated; but the theoretical physicist by his terrestrial studies has worked out for us the required equation. (Incidentally he has worked it out wrong—but that is another story, and I'll speak about the white dwarfs later. For the present we will keep to the ordinary stars.)

The internal temperatures determined in this way are of the order 10 to 20 million degrees Centigrade. Having ascertained this, we begin to realize the state of things that we have to deal with. At this temperature all the atoms will be highly ionized. Light elements such as oxygen will be stripped bare to the nucleus, and heavy elements such as iron and lead will retain only a few of the innermost satellite electrons. The rest of the electrons will be free. We have therefore to deal with a population consisting of free electrons, the shattered remnants of atoms and photons or quanta of radiation. Planck's law determines both the amount and kind of radiation present at a given temperature. At 10 to 20 million degrees the radiation consists of rather soft X-rays.

Now we can see more or less what is happening at 10 million degrees in the interior of the sun. Crowded together within a cubic centimeter there are more than a quadrillion atoms, about twice as many free electrons and 20,600 trillion X-rays (British reckoning). The X-rays are traveling with the speed of light, and the electrons at 10,000 miles a second. Most of the atoms are hydrogen atoms or rather, since they have lost their satellite electrons, simply protons traveling at 300 miles a second. Here and there there will be heavier atoms such as iron lumbering along at 40 miles a second. I have told you the speeds and the state of congestion of the road; and I will leave you to imagine the collisions. Small wonder if the atoms are found with their garb of electrons badly torn or even stripped naked.

The stripped atoms are continually capturing free electrons and, so to speak, repairing their dress; but scarcely has the captured electron settled when an X-ray bears down on it and explodes it away. This is not a fanciful picture. These are phenomena which have been found happening in the laboratory when we use X-rays of the same wavelength and electrons of the same speed as in the sun. There is no need to go beyond the limits of terrestrial experiment to discover what is happening to the population, and all the calculations have an experimental basis.

The atoms and electrons are rushing violently hither and thither; but on the whole they do not get any forwarder; gravitation pulls them back and keeps the material of the star in equilibrium. But the X-rays gradually leak outward. They are subject to gravitation, it is true; but their velocity of 186,000 miles a second is sufficient for escape from any star. It is just the same as in the theory of planetary atmospheres, where gravitation is sufficient to retain the heavier constituents, but the lightest atoms have sufficient velocity to escape. The planet thus loses the lightest gases; and in the same way the star loses (or, as we say, radiates) photons of radiation. I should explain that, although these photons are X-rays in the interior of the star, they are transformed down to longer wave length in passing through the last few thousand kilometers of comparatively cool matter; so that it is in the form of light and heat waves that they finally escape.

So you may picture a photon of radiation, barging first one way, then another, like a man in a rioting mob—absorbed by an atom and flung out again in a new direction. In this way a photon in a star will wander aimlessly round in the interior for a million years or more until, just by accident, it finds itself at the exit of the maze—shoots through—and makes a bee-line across space to the Oakridge reflector, where Professor Shapley photographs it.

Having first ascertained the particulars about the population that I have been describing, we can apply the laws (based on laboratory experiment) which determine the amount of obstruction offered by atoms and electrons to the passage of X-rays, and so find how many photons leak out into space per second. We can compare this result with observation—that is to say, we can see whether Professor Shapley catches as many of them with his telescope as (according to our calculation) he ought to catch—in short, whether the star is actually as bright as our calculation makes it.

In the last few years we have found a complication in the calculation which I must now explain. At an earlier stage we had to ask the physicist to supply a formula giving the temperature of a gas when the pressure and density are known. Not unreasonably he will object: "You have not given me enough information. What *is* the gas?—oxygen? iron vapor? mercury vapor? or what?" We cannot say. But on second thoughts he withdraws the objection. "Never mind. Ordinarily it would make a big difference, but at the high temperatures we are concerned with it makes practically no difference what element we take. The atoms will be almost completely ionized; that is to say, their satellite electrons will be moving as free particles. We only want to know the average weight per free particle. The number of satellite electrons in an atom is roughly half the atomic weight—so that we shall have roughly 2 units of weight per particle; for example, oxygen of atomic weight 16 breaks up into 9 particles, namely 8 electrons and a nucleus; iron of atomic weight 56 breaks up into 27 particles." Owing to this remarkable property it has been possible to make considerable progress with the theory of the interior of a star without knowing what chemical elements it is composed of.

Those are the physicist's second thoughts. But on third thoughts he exclaims, "Bother! There's hydrogen." The rule that there are two units of weight per particle does not work for hydrogen. It has atomic weight 1 and splits up into a proton and electron, so that the average weight per particle is ½—instead of 2. That makes a vast difference.

A year or two ago the physicist had some alarming fourth thoughts about neutrons; but neutrons are absorbed very easily by atomic nuclei, and I think they will have only a transitory existence on the sun, as on the earth, and never form an appreciable part of the population. So we won't worry about fourth thoughts. The crux of the matter is that, for the purposes of these investigations, there are just two kinds of matter, namely, *hydrogen* and *not-hydrogen*. Hydrogen gives a much lower temperature than *not-hydrogen*, and therefore lower brightness for a star of the same mass and radius. Our comparison of theory and observation can therefore be used in two ways. We can calculate the brightness of a star, assuming the material to be *not-hydrogen*, compare it with observation, congratulate ourselves on the partial agreement we find, and ponder over the possible sources of the discrepancies which remain—one possible source of discrepancy will be the presence of a significant proportion of hydrogen. The other way is to try various combinations of hydrogen and not-hydrogen until we find the proportion which gives precise agreement of the calculated and observed brightness. That is the method we generally employ nowadays; the observed brightness of a star tells us what proportion of its mass consists of hydrogen.

Dr. Bengt Strömgren found in this way that the sun, Capella, and other typical stars contain 33 percent of hydrogen. My own calculations agreed precisely. This agreement is rather specially interesting because we adopted different composition for the remaining 67 percent of the mass. Strömgren used a mixture of rather light elements, familiarly known as "Russell's Mixture," believed to agree with the composition of the outer layers determined with the spectroscope; I used a mixture about three times heavier. Our precise agreement confirms what I have already said—that it makes no difference what kind of stellar material you assume, so long as it is *not-hydrogen.* It is still doubtful to what extent the proportion of hydrogen varies in different stars; there is some evidence that it is greater in the most massive stars, but the evidence is not very good. An important paper presented by Prof. H. N. Russell to the Tercentenary Conference was partly devoted to this question.

I must say a word about the agreement of theory and observation. Since we determine the proportion of hydrogen so as to make the observed and calculated brightness agree, we obviously cannot claim that the agreement is a confirmation of the theory. Nevertheless it does furnish a fairly efficient check. Unless the theory were pretty near the truth, we should find that for some of the stars which we try it would be impossible to find any proportion of hydrogen that would bring about agreement. It is satisfactory, therefore, that all the stars give a reasonable proportion. If Strömgren had found, instead of 33 percent, an answer which involved the square root of −1, as might easily have happened, we should have concluded that there was something fishy about the theory.

The recognition of white dwarf stars with density far transcending that of any terrestrial matter is one of the more spectacular developments of the study of stellar constitution. A cubic inch of the matter of the companion of Sirius weighs about a ton, and some of the more recently discovered white dwarfs appear to have higher densities even than that. In order to explain a new point which has arisen in connection with the theory of these stars, I must go back to past history. In 1924 the mass-luminosity relation—that is, the formula expressing the result of the calculation I have been describing—was worked out; and, on comparing with observation, it turned out that it was obeyed not only by the diffuse giant stars for which it was intended but also by the dwarf stars with densities greater than water for which it was *not* intended. This was a complete surprise. But the explanation was not difficult to find. We had been taking it for granted that stellar matter would cease to behave as a perfect gas when the density approached that of ordinary liquids or solids. Ordinary terrestrial atoms then begin to jam together and the material becomes almost incompressible. But in the stars the temperature of 10 million degrees causes most of the satellite electrons to be torn away from the atom, and what is left of the atom is a tiny structure. The atoms or ions are so reduced in size that they will not jam until densities 100,000 times greater are reached. For this reason, the perfect gas state continues up to much higher densities in the stars. The sun and other dense stars insisted on obeying the theory worked out for a perfect gas, as they had every right to do, since their material was perfect gas.

There was, therefore, nothing to prevent stellar matter from becoming compressed to exceedingly high density; and it suggested itself that the densities which had been calculated from observation for certain stars called white dwarfs, which had seemed impossibly high, might be genuine after all.

In reaching this conclusion I was not without a certain misgiving. I was uneasy as to what would ultimately happen to these superdense stars. The star seemed to have got itself into an awkward fix. Ultimately its store of subatomic energy would give out and the star would then want to cool down. But could it? The enormous density was made possible by the high temperature which shattered the atoms. If the material cooled it would presumably revert to terrestrial density. But that meant that the star must expand to say 5,000 times its present bulk. But the expansion requires energy—doing work against gravity; and the star appeared to have no store of energy available. What on earth was the star to do if it was continually losing heat, but had not enough energy to get cold!

The high density of the companion of Sirius was duly confirmed by Professor Adams—but this puzzle remained. Shortly afterward Prof. R. H. Fowler came to the rescue in a famous paper, in which he applied a new result in wave mechanics which had just been discovered. It is a remarkable coincidence that just at the time when matter of transcendently great density was discovered in astronomy, the mathematical physicists were quite independently turning attention to the same subject. I suppose that up to 1924 no one had given a serious thought to abnormally dense matter; but just when it cropped up in astronomy it cropped up in physics as well. Fowler showed that the newly discovered Fermi-Dirac statistics saved the star from the unfortunate fate which I had feared.

I will say a word or two about Professor Fowler's explanation. My colleague Fowler was in his youth a pure mathematician, and I am afraid he has never really recovered from this upbringing. Consequently, although his paper contained reassuring equations, it did not clearly reveal the simple physical modification of ideas which wave mechanics brought about. He proved that the star would manage all right. But, as you may have inferred from Professor Hardy's revelations, I am not an extreme worshipper of proof. I want to know *why;* a proof does not always tell you that. As Clerk Maxwell used to ask, "What's the go of it?" Well, in this case the "go of it" was that whereas the older theory said that atoms could only be ionized by high temperature the new wave mechanics said that high temperature was not essential because they could also be ionized by crushing them under high pressure. Several writers tumbled to it, before I did, that that was what Fowler's rather mysterious result really meant; but I think that it is still not at all generally known. You see this allows the star to cool down and still retain its enormous density—which the older quantum theory did not.

Not content with letting well alone, physicists began to improve on Fowler's formula. They pointed out that in white dwarf conditions the electrons would have speeds approaching the velocity of light, and there would be certain relativity effects which Fowler had neglected. Consequently Fowler's formula, called the *ordinary* degeneracy formula, came to be superseded by a newer formula, called the *relativistic* degeneracy formula. All seemed well until certain researches by Chandrasekhar brought out the fact that the relativistic formula put the stars back in precisely the same difficulty from which Fowler had rescued them. The small stars could cool down all right, and end their days as dark stars in a reasonable way. But above a certain critical mass (two or three times that of the sun) the star could never cool down, but must go on radiating and contracting until heaven knows what becomes of it. That did not worry Chandrasekhar; he seemed to like the stars to behave that way, and believes that that is what really happens. But I felt the same objections as 12 years earlier to this stellar buffoonery; at least it was sufficiently strange to rouse my suspicion that there must be something wrong with the physical formula used.

I examined the formula—the so-called relativistic degeneracy formula—and the conclusion I came to was that it was the result of a combination of relativity theory with a nonrelativistic quantum theory. I do not regard the offspring of such a union as born in lawful wedlock. The relativistic degeneracy formula—the formula currently used—is in fact baseless; and, perhaps rather surprisingly, the formula derived by a correct application of relativity theory is the ordinary formula—Fowler's original formula which every one had abandoned. I was not surprised to find that in announcing these conclusions I had put my foot in a hornet's nest; and I have had the physicists buzzing about my ears—but I don't think I have been stung yet. Anyhow, for the purposes of this lecture, I will assume that I haven't dropped a brick.

I venture to refer to a personal aspect of this investigation, since it shows how closely different branches of science are interlocked. At the time when my suspicion of the relativistic degeneracy formula was roused by Chandrasekhar's results, it was very inconvenient to me to spare time to follow it up, because I was immersed in a long investigation in a different field of thought. This work, which had occupied me for 6 years, was nearing completion and there remained only one problem, namely, the accurate theoretical calculation of the cosmical constant, needed to round it off. But there I had completely stuck. I had, however, secured a period of 4 months free from distractions which I intended to devote to it—to make a supreme effort, so to speak. But having incautiously begun to think about the degeneracy formula I could not get away from it. It took up my time. The months slipped away, and I had done nothing with the problem of the cosmical constant. Then one day in trying to test my degeneracy results from all points of view, I found that in one limiting case it merged into a cosmical problem. It gave a new approach to the very problem which I had had to put aside—and from this new approach the problem was soluble without much difficulty. I can see now that it would have been very difficult to get at it in any other way; and it is most unlikely that I should have made any progress if I had spent the 4 months on the direct line of attack which I had planned.

The paper which I read to the mathematical section a few days ago,[2] giving a calculation of the speed of recession of the spiral nebulae and the number of particles in the universe, had an astronomical origin. It was not, however, suggested by consideration of the spiral nebulae. It arose out of the study of the companion of Sirius and other white dwarf stars.

I mentioned that we only gradually came to realize that ionization could be produced by high pressure as well as by high temperature. I think the first man to state this explicitly was D. S. Kothari. Stimulated by some work of H. N. Russell, Kothari has made what I think is an extremely interesting application. The relation of ionization to pressure is a curious one, for at low pressures we decrease the ionization by increasing the pressure; but the ionization must have a minimum, for at high pressures the Fermi-Dirac complication steps in and the ionization ultimately increases with pressure. No one seems to have bothered much about this revised ionization law; they have been content to recognize, or I think rather to guess, that in white dwarfs the ionization would be pretty high. Kothari, however, has treated it seriously and worked out the degree of ionization in various conditions, including comparatively small masses in which the pressure is relatively low and the ionization is not very high. He has thus obtained formulae which he is able to apply to the planets.

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[2] Amer. Journ. Math., vol. 59, no. 1, 1937.

I turn now to the subject of subatomic energy which we believe to be the source which maintains a star's heat. This is a matter on which, until about 3 years ago, terrestrial experiment gave us no help at all. Conditions have now changed, and physical laboratories throughout the world have given themselves up to an orgy of atom-splitting. It is of immense importance for the future of astronomy that a new laboratory technique enables us to experiment directly on the processes of liberation of energy by transmutation of atomic nuclei, since these are almost certainly the processes which keep the stars alight. But at present it is too early to expect results this way. The theory of stellar constitution, which I have been describing, was built up without any laboratory knowledge of subatomic energy. This was possible because the problem of the source of maintenance of a star's heat could be segregated almost completely from the rest of the problem. By Lane's method we could determine the temperature—how much heat there was in the star—without speculating as to how it came to be there; and we could show that a star so endowed must radiate at the moment a calculable amount of light and heat—without inquiring how it managed to go on radiating it for thousands of millions of years. In short, the structural problem could be segregated from the evolutionary problem.

The only point at which the segregation is not complete is this: The concentration of density toward the center of a star depends to some extent on how the source maintaining the heat is distributed. It seems clear from present-day experiment, as well as from astronomical evidence, that the liberation of subatomic energy increases rapidly with temperature; so that we may expect it to occur mainly in the hottest central part of the star. This has the effect of diminishing the concentration of density to the center—making it less than in the standard model which has generally been employed. This effect is, however, limited; because, if the star overdoes it, convection currents are set up, which bring about compensation. To describe our present conclusion I must use technical terms: The density distribution near the outside has a polytropic index 3 which gradually diminishes to 1.5 at the center, where there is a convective core. I am speaking of ordinary stars such as the sun; but curiously enough this specification of the density distribution applies also to white dwarfs—for which it has long been the recognized model—though in the white dwarfs it comes about in quite a different way.

Apart from this refinement, the researches which I have hitherto described are not affected by theories of subatomic energy. But they put us in a favorable position to learn something about the laws of subatomic energy. Many well-known lines of argument have convinced us that the sun and stars have a lifetime to be reckoned in thousands of millions of years—which means that evolutionary changes are extremely slow, and that the heat radiated by a star into space is almost exactly balanced by the heat liberated from subatomic sources in the interior. So when we measure the radiation of a star, we measure the generation of subatomic energy. You see then that the measurement of subatomic energy is just a common everyday astronomical measurement.

To the engineer the release of subatomic energy on a practical scale is, and seems likely to remain, a Utopian dream. To the physicist it was, until 3 years ago, a field of uncontrolled theoretical speculation. To the astronomer it has long been an everyday phenomenon which it would be absurd to close his eyes to.

Having then measured the rate of release of subatomic energy in all types of stars, we can correlate it to the temperatures and densities which we have found in the interior. This more or less direct investigation of the conditions of release can be supplemented by a theoretical examination of the conditions of stability of stars containing such a source—a line of attack initiated by Prof. H. N. Russell.

If the star contracts, the liberation of subatomic energy must be stimulated; otherwise the star is unstable. We cannot deduce astronomically whether the stimulus comes from the increased temperature or the increased density; but for simplicity we shall suppose it to be mainly the temperature. Then each star contracts until its internal temperature reaches the value at which the liberation of subatomic energy is equal to the heat radiated, and there it sticks—not quite indefinitely, but for a very long period until the sources of subatomic energy show signs of exhaustion. The stars on the main series appear to be those which have reached this balance and stuck. Now it is one of the results of our previous investigations that the stars of the main series, from the most massive to the lightest, have practically the same internal temperature. We used to give the central temperature as 40 million degrees, but the figure has come down—partly by the recognition of the abundance of hydrogen and partly by the substitution of a less condensed model, and the present estimate is about 15 million degrees. But whatever it is, it is nearly the same for all. It appears, therefore, that on the main series a small star which requires a small amount of energy per gram to maintain its radiation and a massive star requiring 1,000 times as much energy per gram both have to rise to 15 million degrees to liberate it. Or to put it another way the liberation must increase 1,000 fold in a rise of temperature scarcely large enough for us to notice in our rather rough calculations.

Another result of the examination of the stability of a star is important. The rate of liberation of subatomic energy must increase with temperature *but not too fast;* if it increases more steeply than a certain limit the star will be thrown into pulsation. Some stars do pulsate, namely, the Cepheid variables, but the majority do not. Perhaps we may infer that the actual law of increase is pretty near the limit, so that the conditions of most of the stars are on the one side and those of the Cepheids just beyond it. But there is a way by which the star can escape this pulsatory instability. We have been supposing that the response of the subatomic energy to the stimulus of temperature is immediate; if there is a lag—if the rising temperature stimulates the formation of active material which emits the energy later on in its own good time, or if it starts a chain of processes of which the actual energy liberation is the last, then there will be no pulsation. A lag of some days at least is required. Provided there is this lag, the stars will be stable, even though the energy liberation increases very rapidly with the temperature—as our observational results for the main series stars indicate and as is also indicated by the recent laboratory experiments.

This is the main information about subatomic energy that we have learned from astronomy. I suppose that, taken altogether, it seems a meager amount. But its importance is considerably enhanced, when we recall that on almost every point it was completely at variance with the views then held by physicists. The only form of liberation of subatomic energy with which physicists were then acquainted was radioactivity—a process independent of density and unaffected by temperature unless the temperature were far higher than 15 million degrees; and they were inclined to be intolerantly disposed toward considering any other process, no matter how strong the astronomical evidence might be. I cannot but think that this is an instance of the harm done by the writers who give the impression that stellar investigation is a field of loose speculation. Physics and astrophysics are one subject, following the same rules of progress, recognizing the same standards of rigorous deduction, and utilizing the same corpus of accepted knowledge; and liable to the same failures through our human limitations.

Various attempts were made to find a loophole for admitting much higher temperatures in the stars so as to satisfy the physicist's objection to admitting energy liberation controlled by low temperature; for example, Jeans's theory of elements of very high atomic weight, and Milne's theory of the existence of a core of white dwarf density in ordinary stars like the sun. We can scarcely say that such suggestions are impossible without attributing to our existing knowledge of the laws of physics greater completeness than we care to claim. But I think it can be said firstly that these theories were found on examination not to fulfill what was initially claimed for them—on the strength of which they were recommended. And secondly it is not unfair to describe them as agreeing with the physicist on a matter as to which he knew nothing, at the expense of disagreeing with him on matters as to which he claimed to know a great deal.

All that has changed now that these subatomic processes have been studied in the laboratory. They are found to require comparatively low speeds of the particles, corresponding to comparatively low temperatures, such as the stellar investigations had indicated. The first criticism I heard, after the experiments on disintegration of elements by protons had begun, was that 40 million degrees was too high a temperature for the sun; and it could not be much over 15 million degrees without blowing up. Happily we had been beforehand; and the revised astronomical calculations had already lowered the temperature to a point which makes the sun safe for posterity.

New experimental discoveries have helped us to come to an important decision as to the nature of the subatomic energy released in the stars. For 15 years we have been hesitating between two alternative suggestions. The energy might be provided by electrons and protons annihilating one another, thus setting free the whole energy of their constitution in the form of radiation. Or it might be provided by transmutation of the elements. Even in this application it remains true that we need distinguish only two kinds of stellar matter, namely hydrogen and not-hydrogen; so the transmutation can be more precisely defined as the transmutation of hydrogen into not-hydrogen. The annihilation of a proton by an electron corresponds to the complete disappearance of a hydrogen atom. The energy released by the transmutation of a hydrogen atom into other elements is only about $1/_{120}$ of the energy which would be released by its complete disappearance. Thus the annihilation hypothesis provides more than 100 times as much energy as the transmutation hypothesis; and the possible lifetime of a star is correspondingly increased.

Attempts to decide between the two alternatives by astronomical evidence were inconclusive. But recent progress in physics seems to point decidedly to the transmutation hypothesis; and the annihilation hypothesis seems to have been generally abandoned. Perhaps the most serious blow to it was the discovery of the positron by Anderson at Pasadena. The positron, not the proton, is the true opposite of an electron; and positrons and electrons *do* annihilate one another. Our lust for slaughter being thus satisfied, it would be incongruous to bring in the proton as an alternative agent; and we look on the supposed annihilation of electrons by protons as a rather misdirected anticipation of the real cancelling.

Simultaneously the very long time-scale, which corresponds to the annihilation hypothesis, has lost its attractiveness. The phenomenon of the expansion of the system of the galaxies which constitutes our universe, as well as studies of the stability of individual galaxies, make it difficult to assign an age to the stars greater than 5,000 million years. The radiation required for this period is amply provided for by the transmutation hypothesis, and the hundred fold greater energy provided by the annihilation hypothesis would only be an embarrassment.

Both hypotheses were originally theoretical suggestions; but the transmutation hypothesis can now claim a definite observational basis. Take the sun, which we have found to be one third hydrogen and two thirds not-hydrogen. At 15 million degrees the hydrogen is ionized and its nuclei—*i. e.*, the protons—are traveling at average speeds of 500 miles a second. We know that in the laboratory protons of this speed attack and enter the nuclei of other elements—the not-hydrogen—and bring about transmutations in them. We may hope that in due time the physicists will be able to trace for us the whole sequence of changes direct and indirect which result, so that we shall be able to find quantitatively the rate of disappearance of free hydrogen under these conditions, and so find the amount of subatomic energy of this kind liberated in the sun. If it is found to agree with the sun's rate of radiation, we shall then have definite proof that no other source—such as annihilation—is operative. We are, of course, far from having the necessary knowledge at present. It is complicated by the fact that, although the protons enter atomic nuclei and change the nuclei into new elements, in many cases the new nucleus breaks down after a short time, a proton is shot out and no permanent transmutation results. Such permanent transmutation as is observed comes at the end of a chain of processes of which the attack of the proton on the nucleus is the first. It is interesting to notice that this was already foretold by the astronomical investigations which, as I have said, demand a time-lag between a stimulation of the activity of the protons by rise of temperature and the corresponding increase of output of subatomic energy.

I have given you my impression of the way in which this new knowledge works in with, and so far as we can see, agrees with the existing theory of stellar constitution, not because I lay stress on the rough conclusions that can be drawn in the turmoil of new discovery—the data available at present are far too scrappy—but because I want to show how intensely important for astronomy is the work of atom-splitting now in progress—so that we may look forward to great developments in the future.

DISCOVERIES FROM SOLAR ECLIPSE EXPEDITIONS[1]

By S. A. MITCHELL

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[With 9 plates]

Throughout all ages of the world's history, the coming of a total eclipse of the sun has always been regarded with fascinating interest. Even today in some less civilized portions of the globe, a dragon is believed to be devouring the sun, with the result that the monster must be scared away by the beating of tom toms or must be appeased by the making of sacrificial offerings. The present-day appeal to intelligent people is a twofold one: first and foremost, on account of the spectacular character of the phenomenon, the coming of darkness during the daytime, and the matchless beauty of the corona, and second, on account of the apparently uncanny skill with which the astronomer is able to predict hundreds of years in advance the exact hour and minute when the darkening will take place and the location on the earth's surface where the phenomenon may be observed.

The modern scientific method of investigation, that of experimentation, came into vogue about the time of the 1842 total eclipse which was greeted at Milan with shouts of "Long live the astronomers," who had provided so beautiful a phenomenon to please and interest the populace. The unexpected beauty of color and form of the prominences and the corona, coupled with the discovery of Baily beads, and in the year following the discovery of the periodicity of sunspots, caused an unprecedented increase in interest in the physical constitution of the sun. If one of our present-day enthusiastic eclipse astronomers had been alive at that time and with long life and unimpaired vigor had been permitted to take part in each eclipse expedition from that day to this, and if he had had to take his average run of luck with the weather, he would have been permitted 1 precious hour of 60 golden minutes to secure all of his observational material. Among all the wonders of modern science, it is safe to state that the eclipse astronomer eclipses the performances of any other scientist in the wealth of information gleaned per hour spent in securing the observations.

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[1] The sixth Arthur Lecture, under the auspices of the Smithsonian Institution, February 9, 1937. The author observed his tenth solar eclipse as the scientific leader of the National Geographic Society—U. S. Navy expedition to Canton Island. Through the kind permission of the National Geographic Society we are enabled to publish photographs from this latest eclipse, that of June 8, 1937.—EDITOR.

Photography was employed with success at the eclipse of 1860, and by its means it was proved that the prominences belonged to the sun. The first triumph of the spectroscope at eclipse time was the discovery of helium in 1868, though it was not isolated as an inert gas until 1895. Coronium was discovered in 1869, but even today we do not know its physical constitution. Before the eclipse of 1870, Young foretold a sudden change in the appearance of the spectrum of the sun at the time of the beginning of totality, from dark lines on a bright background to the sudden flashing out of bright lines on a dark background. His were the first eyes to see the spectrum of the chromosphere called by him the "flash spectrum" which was first photographed but very imperfectly at the eclipse of 1893. With better and better photographic plates, each eclipse, especially since 1900, has been assiduously observed, distances away from home and difficulty of access being no insurmountable obstacles to the eclipse observer. One of the most spectacular discoveries from eclipses came in 1919 with the verification of the relativity shift as predicted by Einstein. Succeeding eclipses gave a more complete verification. In the following pages will be given a more detailed account of the chief discoveries from the most recent of eclipse observations.

There are many different kinds of eclipses: Eclipses of the sun and moon, eclipses of a star by the moon, eclipses of Jupiter's and Saturn's satellites, and eclipses of one star by another of a binary system. Observations of eclipsing binaries have given valuable information regarding the masses and densities of stars—but for lack of space the subject cannot be treated here.

The accuracy with which the times of solar and lunar eclipses can be predicted depends on the reliability of the work of astronomers of all ages, and the manner in which the torch of learning has been handed on from one generation to the next. The motion of the earth about the sun is now known with a very high degree of accuracy. In spite of the refined researches on the motions of the moon, the place in the sky of our unruly neighbor is yet not known with a sufficient degree of precision. Tables of the moon are used for calculating the place of the moon in the nautical almanacs prepared by different national governments some 3 years in advance. For these almanac positions it is desirable to keep the theory of the moon as free as possible from arbitrary empirical terms so that the lunar theory may not be cluttered up. When observations are secured, the results can be compared directly with theory. Between the theoretical position of the moon given by the almanac and the observed place there may be a difference of several seconds of arc.

For long-range predictions of lunar or solar eclipses the simplest method is to refer to Oppolzer's *Canon der Finsternisse* where are given the elements of all the eclipses (8,000 solar and 5,200 lunar) between the dates 1208 B. C. and A. D. 2162, together with charts of the earth showing the locations where total and annular solar eclipses may be observed. Oppolzer's predictions became possible on account of the fact that the moon repeatedly takes nearly the same position in the sky with reference to the sun and earth as is shown by the following values:

	Days
19 eclipse years	6,585.7806
223 synodic months	6,585.3211
242 nodical months	6,585.3572
239 anomalistic months	6,585.5374

More than 2,000 years ago it was known to Hipparchus that the moon's node was not fixed. Nineteen returns of the sun to the node or 242 of the moon take place in 6,585 days, an interval of time known to the Chaldeans as the *Saros* (meaning "repetition"), which is equivalent to 18 years 11 days or 18 years 10 days depending on whether 4 or 5 leap years intervene. The author observed his first total solar eclipse in Georgia on May 28, 1900. In 1918 he had to travel westward to Oregon to observe the eclipse of June 8. The following eclipse in the Saros occurred on June 19, 1936, and was observed in Soviet Russia and in Japan. The chart on plate 3 shows 44 total eclipses in the series which includes the eclipse of August 31, 1932. This series in A. D. 1211 began near the earth's South Pole and the eclipse tracks will pass off the earth near the North Pole in the year 1985, so that for 775 years this eclipse has been repeating itself again and again after the lapse of the Saros interval. Three times this interval is 54 years and 1 month, and it is seen from the chart that the eclipse track is fairly parallel to the one 54 years earlier but farther north. In such a series of solar eclipses there are between 68 and 75 repetitions, depending on circumstances, extending over some 1,200 years. In each series there are approximately 25 partial and 45 central eclipses. These numbers vary for different series. Of the central eclipses, total eclipses follow total eclipses with about the same duration of totality and annular eclipses follow annular eclipses. If eclipses take place at the moon's descending node, the eclipse tracks come on the earth at the South Pole and move north, whereas if eclipses occur at the ascending node the eclipse tracks start at the North Pole and move southward.

According to Oppolzer, there are on the average 237.5 solar eclipses in a century, or more than 2 solar eclipses per year. There are 83.8 partial, 77.3 annular, 10.5 annular and total (the vertex of the moon's shadow just reaching the earth), and 65.9 total solar eclipses. On the average, therefore, two total eclipses are visible in 3 years. The chart showing the series including the 1932 eclipse shows that the succeeding eclipses are difficult of access and therefore will probably pass unobserved, hence a total solar eclipse is actually observed about once every other year. In the years 1900–36, expeditions have attempted observations on 18 separate eclipses.

In a third of a century there were five total eclipses observed in the United States, those of the years 1900, 1918, 1923, 1925, and 1932, but in the coming half-century only the two eclipses of 1963 and 1970 can bring scientific results of value, though two other eclipses in 1945 and 1954 will begin at sunrise about on the Canadian border. Hence, the present generation of American eclipse observers must make long trips from home if the scientific reputation of the country is to be maintained.

The total number of eclipses, solar and lunar, partial and total, that may occur in 1 calendar year varies from a minimum of two to a maximum of seven. The number of solar eclipses in a year varies from two to five. In the years 1922, 1926, 1929, 1933, 1940, 1944, 1951, and 1962 there are two eclipses only, both of the sun. In 1935 there were two lunar and five solar eclipses, a combination that will not take place again until the year 2485. In 1982, there will be three total lunar eclipses and four partial solar eclipses.

Taking the earth as a whole, there are more solar eclipses than lunar in the ratio of 4 to 3. It has been calculated that on the average a total eclipse of the sun visits a locality once every 360 years. The maximum duration of totality at a solar eclipse is 7 minutes 30 seconds. On June 8, 1937, totality will last 7 minutes 4 seconds. The eclipse may be observed from a few small islands in the Phoenix group about 8 o'clock in the morning when totality will last a little more than 4 minutes. Thirty-five minutes before sunset the eclipse will reach Peru, where duration is 3 minutes 20 seconds, and an altitude of the sun of only 8° will make scientific observations difficult.

The inhabitant (and we believe there are none) on Jupiter or Saturn would have frequent opportunities to observe total eclipses, both of the sun and of the moons. If our own fair Luna were 25,000 miles farther off from the earth, or if its diameter were 10 percent smaller there would never be a total solar eclipse. What a dreary old world this would be, especially for poets and lovers, if the earth resembled Venus in having no moon!

TIMES OF CONTACTS

The position of the moon is furnished from the times of contact of the limbs of the sun and moon. The time of first contact, or the beginning of the eclipse, is difficult to observe visually with accuracy, since nothing is to be seen at the edge of the sun until the moon is projected on the sun's face—and first contact has actually taken place. Fourth contact, the end of the eclipse, is easier to observe, since the moon may be followed in a telescope of low power until it leaves the face of the sun. Second and third contacts, the beginning and ending of totality, can be determined with greater accuracy. By means of photographs taken throughout the partial eclipse, both before and after totality, the relative positions of the sun and moon can be determined with a much greater accuracy than can be obtained visually, and in addition many more observations are available than the four times of contact.

At the eclipse of 1905, totality came ahead of the predicted time by 20 seconds, in 1918 by 12 seconds, and in 1922 by 16 seconds. For guiding the work of the eclipse astronomer, it is now deemed desirable to know the times of beginning and ending of a total solar eclipse within an error of a few seconds. Accordingly, it has become customary in recent years to secure from Washington or Greenwich, a month or more before the eclipse takes place, corrections to the almanac positions of the moon.

On account of the difficulty of seeing the moon when near the time of new moon, there is ordinarily a gap in the regular lunar observations, whether these are made by occultations or by meridian circle. An intense interest was aroused in the United States by the total eclipse of January 24, 1925, which was visible to almost one-tenth of the total population of the country. From large numbers of careful observations it was hoped that it might be possible to obtain a very high degree of accuracy and thus permit a comparison of different methods of observation in order to detect any systematic errors peculiar to any one method. For predicting the eclipse it was necessary to add a correction of $7.''0$ to the mean longitude of the moon as given in the American Ephemeris. The times of second contact by skilled observers with every facility for obtaining accurate positions of their stations and accurate time signals on eclipse day differed from locality to locality by over 4 seconds, and the duration of totality had a range of 6 seconds, variations in fact much larger than were expected. However, it must not be forgotten that the outline of the moon departs greatly from a perfect circle and that the time of the beginning and ending of a total solar eclipse depends very largely on the character of the lunar surface at the point of contact, the beginning of the total eclipse not taking place until the last Baily bead has disappeared. The comparison of the different methods shows that the meridian observations of the moon differed widely among themselves. Occultations and eclipse results agreed with each other within their probable errors, but there were systematic differences from the meridian observations. To obtain greater accuracy, observations must be continued at each succeeding eclipse. Times furnished by observations of eclipses give information not only about the motion of the moon but also about the time of diurnal rotation of the earth on its axis, with the result that an observation of an eclipse of the sun made 3,000 years ago has an important bearing on recent refined researches on the motion of the moon.

THE CORONA

The total light of the corona is roughly one-millionth that of the noonday sun or one-half that of the full moon. The coming of a total eclipse, particularly the last few seconds before totality, the engulfing shadow of the moon coming from the west, the sudden coming of darkness and then the gorgeous corona make a never-to-be-forgotten spectacle, still further enhanced by the beauty of the rosy red prominences. Regarding the 1925 eclipse, the New York newspaper folk state that no phenomenon of modern life had so many words written per unit of duration of the event as that particular eclipse.

The corona may be photographed by cameras large or small, fast or slow. In spite of the excellent qualities of modern photographic technique, it is still impossible to get an adequate photograph that will represent all the details of the corona that are readily visible to the naked eye. The inner corona is very brilliant, while the outlying portions of the coronal streamers fade off gradually to nothingness. From the lofty perch of Pike's Peak in 1878 the corona was detected to 12 diameters from the sun's edge, a distance of over 10 million miles. An exposure long enough to portray the faint outlying streamers will have the inner corona quite burnt out through overexposure.

With cameras of great length it is necessary to counteract by mechanical means the diurnal motion. This may be done by mounting the telescope horizontally and then using a coelostat mirror or by pointing the object glass directly to the sun by means of erecting a tower. In 1900 the Smithsonian Institution used a camera of 135 feet focus, and its great length required it to be arranged horizontally. Unfortunately, the heat of the sun may warp the plane mirror of the coelostat and spoil the focus. The result has been that in recent years, when exact definition is desired, it is obtained by a camera pointed directly at the sun. For moderate focal lengths up to about 15 feet this may be obtained by mounting on a polar axis, but for greater lengths the tower telescope is necessary with the diurnal motion counteracted by a motion of the photographic plate. The Swarthmore astronomers have obtained exquisite definition with focal lengths of 63 and 65 feet. Equally good definition may be secured with cameras of 15 feet focus mounted on a polar axis. The question is whether it is more desirable to photograph on the smaller scale and then enlarge four times if the greater scale is needed or to obtain scale without enlargement by the greater focal length. As for the final definition of the large-scale photographs, there is little to choose between the two methods. The individual astronomer must decide the problem for himself, depending on a number of factors, chief among which is the equipment he owns and the experience he has had. Then he must decide whether it is more convenient and cheaper to take from home the complete polar axis and mounting for the shorter focal length or take the plate holders and the clock mechanism for moving the plate and then build the tower from materials that may be found locally.

It is interesting to note that at eclipse expeditions success has always been greater in the direct photography of the corona than in any other branch of the investigations. The self-evident reason is that every well-equipped expedition, no matter what their other programs, attempts to photograph the corona and usually with several cameras. However, there is another reason not so apparent, which is that perfection of focus and seeing, although desirable, are not absolutely essential in obtaining successful photographs of coronal details. A lack of perfect focus plays havoc with spectroscopic photographs but detracts little from the corona for the reason that its structure is nebulous or filmy in detail. However, no astronomer will be satisfied with anything short of absolute perfection in the determination of the best focus.

THE SHAPE OF THE CORONA

The general form of the corona can be predicted in advance of the eclipse. Near sunspot minimum are found the extended streamers along the sun's equator and the short plumelike polar brushes, whereas near times of spot maxima the corona is nearly circular in shape, thus resembling a gigantic dahlia. Fortunately, photographs of all scales except the small can be utilized to determine the coronal shape by a very simple type of measurement devised by Ludendorff, of Potsdam. In the author's Eclipses of the Sun, 1935 edition, page 500, a chart gives all the eclipses since 1893 successfully observed (but not including 1936). The surprising fact is that the most elongated type of corona does not take place exactly at sunspot minimum, or at phase zero of the curve. As the interval from maximum to maximum is 11 years, it is seen from the chart that 2 years or more before spot minimum the corona is quite as elliptical as at zero phase. The most pronounced ellipticity takes place 1¼ years before minimum of spots, and likewise the corona closest in shape to a circle takes place 1¼ years before spot maximum. The recent eclipse of 1932 took place 1.2 years before spot minima and yet its shape placed it at the highest point of the curve. The succeeding eclipse of 1934 was only 0.2 years after spot minimum but instead of having a pronounced ellipticity the corona had lost its minimum type characteristics. The 1936 corona 2.4 years after minimum spots, in shape resembling an irregular five-pointed star, had lost all of the minimum features except the brushes at one pole. Although about 1 year ahead of the predicted spot maximum, the corona of 1937 will be more nearly circular than that of 1936 and will be the typical sunspot maximum eclipse.

MOTIONS IN THE CORONA

Although the shapes of the corona at spot-minimum all resemble each other in having long equatorial streamers and pronounced polar brushes, yet each corona has its own distinctive features with the result that one corona could never be mistaken for another. In the circular coronas corresponding to maximum of spots the streamers shoot out at various angles differing in each eclipse. We are, therefore, forced to the conclusion that changes are continually going on within the corona. Beginning in 1889, attempts have been made repeatedly to measure these changes. It is evident that the greater the interval of time between the photographs to be compared at two stations the higher will be the accuracy. A splendid opportunity was presented in 1905 when the Lick Observatory established three stations, each with a camera of 40-foot focus, one in Labrador, one in Spain, one in Egypt. Unfortunately for the success of the scheme, it was totally cloudy in Labrador, there were thin clouds in Spain, and, although clear in Egypt, the definition of the photographs was poor. At the American eclipse of 1918, from a comparison of Lick and Swarthmore photographs, it seemed likely that motions of the order of 10 miles per second were found in the coronal arches overtopping prominences. However, at the eclipse of 1926, a comparison of photographs made in East Africa and Sumatra revealed that, if the coronal domes moved at all, the velocities were probably not greater than 1 mile per second.

Much valuable information regarding coronal disturbance was obtained on Niuafoou Island in 1930. This was the first time in the history of eclipses that so much detailed structure was visible in the spectral lines of the corona, this structure being made possible by the fine definition of the grating spectra taken without slit. A comparison of all the 1930 spectrograms, but more particularly the *H* and *K* lines, reveals the interesting fact that 2 years after sunspot maximum the sun was in a condition of great activity on the day of the eclipse. The coronal rings of the spectra and the direct photographs taken with the 63-foot tower telescope show prominences completely circling the sun. Comparisons were also made with spectroheliograms on 4 successive days, taken at Mount Wilson or Kodaikanal. The superb definition of the eclipse photographs showed both the prominences and inner corona in great beauty.

A comparison of all the photographs, the spectroheliograms with the eclipse plates both direct and spectrographic, showed that the great activity of the sun was found not only at eclipse time but persisted throughout the whole period of 4 days covered by the plates. The direct photographs and the eclipse spectra show that the whole southeast quadrant was a tremendously stormy region on the sun. The center of the longest coronal streamer was situated 30° to the east of the south point of the sun. Intertwining the coronal streamers was a beautiful series of coronal domes connected with an extended prominence group. Greater heights were attained by another group of prominences, at position angle 115°, the location of a conspicuous feature called the "strawberry dome," with its magnificent arches and delicate structure of filamentous details. On plate 4, drawings near this particular dome are given for comparison; at *A* from the *K* and *Hα* lines of the spectra of the chromosphere, at *B* three drawings of the same region from the direct photographs and from the lines 5303 and 6374 of coronium, respectively. At *C* on the western edge of the sun, the details in the green coronal line at 5303 result in forms similar to the coconut palms that grow so profusely on "Tin-Can" Island.

For many years eclipse observers have called attention to the connection between coronal streamers and prominences. This dependence was abundantly verified in 1930, but this eclipse demonstrates the fact that the longest coronal streamers, on which the shape of the corona more or less depends, are always located near prominences but are not necessarily exactly connected with the prominences which at the time of the eclipse are of the greatest height.

PHOTOGRAPHING THE CORONA OUTSIDE OF AN ECLIPSE

In 1882, when a bright comet was seen close to the eclipsed sun, attempts were started to photograph the corona without waiting for an eclipse. A decade later, the spectroheliograph was developed, and prominences were readily photographed in full sunshine with the result that attempts were renewed on the corona. In order that the glare of the earth's atmosphere be reduced as much as possible, mountain tops like Pike's Peak or Mount Etna were occupied. No success whatever being obtained, a series of attempts were made by heat-measuring instruments like bolometers or photoelectric cells. Each and every one of the plans, at times carried out with great skill and ingenuity, resulted over and over again always in the same manner—failure to photograph the corona. The measures made by Abbot in 1908 and by many others since then have shown the cause of the failures, namely, the intrinsic feebleness of the coronal light. Even in its brightest parts, the inner corona is no brighter than the surface of the full moon. The corona is about equal to the intensity of the illuminated sky at 8° or 10° away from the sun's edge.

In 1930 and in later years Lyot of the Meudon Observatory has had brilliant successes where others had repeated failures. His great triumph resulted from the ingenious arrangement of his telescope to reduce to a minimum the amount of scattered light inside the instrument. A mountain observatory on the Pic du Midi (9,100 feet) and at times very transparent skies permitted photographs when the scattered sky light was less than five-millionths that of the sun. Lyot not only was able to photograph the brighter parts of the inner corona but by the use of a spectrograph he determined the wave lengths of many coronal lines including three lines in the infrared not yet observed in eclipses.

THE LIGHT OF THE CORONA

Our knowledge regarding the distribution of light within the corona is in a very unsatisfactory state since the law of intensity has been found by various observers to be inversely as the second, fourth, sixth, seventh, eighth, and powers such as 2.3 or 2.4, of the distance measured either from the center or from the edge of the sun. It is of great importance that a well-devised form of apparatus be constructed for use at eclipses, and that photographs be secured both in the violet and visual regions on a carefully prepared plan at several future eclipses. The eclipse photographs should have calibrated squares impressed on them from a standard source, and if in addition photographs of the full moon were obtained, we should then be in a position of having information additional to that acquired during the progress of the eclipse. We need to know whether the distribution of light within the corona follows the same law at every eclipse, or whether this law varies according to the sunspot period, and we need to know the law both in the blue and the yellow regions. Many coronas have been observed through clouds or haze or with varying conditions of transparency. The intensity of the silver deposit measured on the photographs is a summation of two separate effects, one due to the corona itself, the other to the diffuse light of the sky. Added to these, there is in reality a third effect found close to the moon's limb, a halo caused by reflection from the glass-side of the plate of the strong illumination of the inner corona. Unfortunately, it has not been possible to make proper allowances for these varying factors, with the result that observations are affected by large systematic errors.

In considering the measurements made for determining the total light of the corona, there are similar evidences of large systematic errors depending on transparency conditions at the time of the eclipse. A few examples may be given to show the wide divergent results obtained at the same eclipse by different methods and at different eclipses by the same methods and instruments. Harvard Observatory devised a photographic photometer which has been used since the 1925 eclipse. Various types of illumination meters are also used visually which can furnish a measure of the total illumination of corona plus diffused sky light. Measures made with the photographic photometers at the eclipse of 1925 and 1926 seemed to show the corona 40 percent brighter in 1926 than in the year previous. Visual work with the illumination meter in 1925 gave 0.24 foot-candles as the result; in 1926, 0.14 foot-candles; and in 1929 and 1930, 0.15 and 0.38 foot-candles, respectively, the eclipses from 1926 to 1930 being measured by the same instruments.

These measures seemed to show that although the 1926 corona was 40 percent brighter than that of 1925, the total illumination of corona and sky together was 40 percent fainter.

Following the 1932 eclipse, when many measures were made in the United States, one competent illumination expert voiced his opinion of attempts to measure the total light of the corona by the use of illumination meters in the following words: [2]

> There can be no objection to anyone measuring the normal illumination on a completely exposed test plate at the time of totality if he is convinced of the utility of so doing. Trouble, however, may ensue when the results of such measurement are seriously put forward as indicative of the amount of light which the corona is giving.

Hence, it is evident that we must not now take too seriously the attempts to correlate intensity of coronal radiation with sunspot activity. It seems very highly probable that the inner corona at sunspot maximum must be brighter than at spot-minimum. Moreover, as the inner corona contributes the greatest part of the energy of the total coronal radiation, we would logically expect that the total energy at maximum of spots is greater than at minimum. Unfortunately, eclipses come but seldom and there are few observations with which to derive correlations. Many astronomers (and other scientists as well) have come to hasty conclusions through the discussion of observations affected by large accidental and systematic errors. When we consider the paltry amount of time devoted to the measurement of the light of the corona, we must not be too much discouraged at the meager and conflicting results obtained.

In spite of all the inconsistencies of the results, observers throughout the past 50 years have been in agreement that the total light of the corona is roughly one-half that of the full moon. It is with a note of surprise that we read [3] the statement by Menzel and Boyce that the latest corona observed, that of 1936, shone with an illumination of 50 to 100 times that of the full moon. We shall await the detailed results with great interest.

POLARIZATION OF THE LIGHT OF THE CORONA

Polarization measures must be the result of a combination of the partly polarized light from the corona and the unpolarized light in the earth's atmosphere. The measures made of eclipses in the early years of the present century seemed to show that the percentage of polarization in photographic light was about three times greater than in visual light, a result quite in agreement with the assumption that the coronal radiation is Rayleigh scattering from atoms or ions. At the eclipse of 1932, however, photographic measures by Dufay and Grouiller proved that the amount of polarization was entirely independent of wave length and was a maximum of 26 percent in the corona at 10′ from the sun's edge. At the succeeding eclipse of 1934 Johnson found a maximum of 28 percent polarization at 8′.5 from the sun's limb, a result in good agreement with the 1932 eclipse. Evidently the scattering of light in the corona cannot be caused by atoms or ions.

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[2] Journ. Optical Soc. Amer., vol. 23, p. 234, 1933.

[3] Technology Rev., November 1936.

THE SPECTRUM OF THE CORONA

It may be said that the corona exhibits three separate spectra: First, the emission spectrum of "coronium" existing in the inner corona and extending on the average to 5′, or 200,000 km from the sun's edge; second, the continuous spectrum (without lines), of the middle corona; and third, the Fraunhofer lines showing feebly in the inner corona.

In the Revised Rowland Tables (1928) are given a list of 40 bright lines attributed to the corona by Campbell and Moore. Of this list of lines more than half, or 22, appear to take their origin in the high chromosphere. Only 23 emission lines in the corona are known with certainty at the following wave lengths: 3328, 3387.96, 3454.13, 3600.97, 3642.87, 3800.77, 3986.88, 4086.29, 4231.4, 4311, 4359, 4567, 4586, 5116.0, 5302.90, 5536, 6374.30, 6701.8, 7059.6, 7891.9, 8024.2, 10746.8, and 10798.0. Other faint lines are suspected but not yet verified. The green line of 5303 (discovered in 1869) and the ultraviolet line at 3388 have the greatest strengths.

In comparing the green and red coronal rings obtained in 1930 on spectra taken with grating and without slit, it was surprising to find how little they resembled each other in their structural details of greatest strength and how little either resembled the high-level lines *K* and *Hα* of the chromosphere. It was further found that the radiation of 6374 always sticks close to the sun's edge and is more concentrated and more uniform in distribution than 5303. It is evident, therefore, that these two lines cannot take their origin in the same atom, or at least not in the same atom in the same state of ionization.

In order to determine the atomic origin of "coronium," several authorities have grouped coronal lines together depending on the similarities in appearances or distribution of light in the spectral lines. As the radiation of 5303 is very unevenly distributed around the sun, it is evident that spectra taken with slit will be badly handicapped in detecting similar structural details, especially when in many of the coronal spectra the definition is none too good. The only groups to which most authors agree are 5303 and 3388 put together, the strongest lines of the spectra, and 4086 with 3601. As stated above, 5303 and 6374 cannot be placed in the same group.

Without an eclipse Lyot found that the green and red lines and also 6702 have widths of about an angstrom. His wave lengths combined with the best values from eclipses are the values given above. His wave length for the red line, however, differs by 0.2 angstrom from the best eclipse value which gives further evidence of the fact that better wave lengths of the coronal lines are urgently desired.

With the great advance made in recent years in atomic structure, there have been many attempts to find the origin of the mysterious coronium. The general consensus of well-informed opinion seems to be that although neutral oxygen may eventually be found to be one of the chief constituents of coronium, at present that fact is far from being proved. In brief, none of the scientific guesses made up to date have been verified by observational evidence.

SPECTRUM OF THE MIDDLE AND OUTER CORONA

In addition to the bright line spectrum caused by the hypothetical element "coronium," the corona shows the continuous spectrum in the inner corona and dark lines in the middle and outer corona. In 1929, with three spectrographs, Grotrian obtained spectra of the corona which were compared with the solar spectrum taken with the same instruments but weakened by known amounts. Measurements of intensities give the following interesting results: (1) The position of energy maximum in the coronal spectrum is independent of the height in the corona and agrees exactly with the energy maximum in the solar spectrum; (2) within the errors of measurement, the distribution of energy in the coronal spectrum is independent of height in the corona and is identical with the intensity of radiation in the solar spectrum. After many years of uncertainty and conflicting evidence, we at last seem to have the positive information that the color of the corona is identical with that of the sun, or in other words, the corona derives its radiation from scattered sunlight.

In the remarkably clear sky at the Australian eclipse of 1922, Moore seemed to prove quite conclusively that the Fraunhofer lines in the middle and outer corona have their origin in the corona itself and are not caused by sunlight scattered in the earth's atmosphere. By means of a registering photometer, Grotrian measured the widths of the stronger Fraunhofer lines in the coronal spectrum of 1923. These widths were compared with those of the solar spectrum taken by the same spectrograph but weakened by known amounts. In every case the widths of coronal lines were compared with the widths of both stronger and weaker solar spectra. Heretofore, nearly all observers have been in agreement that the coronal lines looked both wider and less distinct than similar lines in the sun. On the contrary, the photometer measures make clear that the dark lines in the coronal spectrum are certainly much less distinct through lack of contrast than in the solar spectrum and, moreover, the dark lines are more prominent in the outer corona than in the inner, but nevertheless the widths of the coronal lines are the same at all distances out from the sun's surface, and within errors of measurement are identical in width with the corresponding lines in the solar spectrum. From similar measures carried out on the 1922 and 1932 spectra, Moore confirms Grotrian's measures of the 1923 spectra.

WHAT IS THE CORONA?

According to Rosseland, the corona has "stimulated speculation to the breaking point, it being even suggested that there we witness our recognized physical laws set at naught by nature itself." It is evident that the cause of the coronal radiation cannot be found in the emission spectrum of coronium which extends no more than 5′ from the sun's edge. As the coronal streamers have been detected to distances 300 times greater, the explanation for the mysterious light of the corona must be found in the radiation causing the continuous spectrum of the inner corona and the dark-line spectrum at greater distances from the sun. The spectra taken in 1923 showed Fraunhofer lines on the face of the dark moon. On the assumption that these were caused by coronal light scattered either in the earth's atmosphere or in the spectrograph, Grotrian was able to apply corrections to the measured intensities of the dark lines in the coronal spectrum. These corrected intensities show that near the sun's edge the continuous spectrum is much stronger than the Fraunhofer spectrum so that no lines are visible, owing to lack of contrast, in the inner corona, though no doubt dark lines may be there. At increasing distances from the sun's edge outward, the intensity of the continuous spectrum falls off more rapidly than the dark-line spectrum. At an angular distance of 19′.5 on the east side and 14′.5 on the west side, or at an average of one solar radius, the intensities of the continuous and the Fraunhofer spectra are equal. At increasing distances from the sun's surface, the dark lines become gradually more readily visible owing to increased contrast on account of the diminished intensity of the continuous spectrum.

Spectra taken at many eclipses during totality have shown the *H* and *K* lines and the stronger hydrogen lines in great intensity, even across the face of the dark moon. These spectral lines take their origin in light from the high chromosphere scattered by the earth's atmosphere, particularly near the beginning and ending of totality. It, therefore, may be quite unsafe to assume that the lines of the spectrum on the face of the moon in 1923 were actually caused by scattered light emanating from the corona rather than from sunlight reflected by nearby clouds in the earth's atmosphere. This, however, is a mere detail on a fine piece of work by Grotrian, and it is evident that the measures must be repeated at future eclipses when, it is to be hoped, the sky will be clear from passing clouds and haze.

As a result of many different theories, it is now generally recognized that the electron must play an important role in explaining the radiation of the corona. If the continuous spectrum is caused by free electrons which scatter the solar radiation, it is found that at a temperature of 4,000° K., the average thermal velocity of the electron would cause a Doppler effect of the order of 10 angstroms. As a result, all of the Fraunhofer lines would be wiped out with the exception of the broad wings of the *H* and *K* lines.

Electron scattering, therefore, furnishes an adequate explanation of the absence of dark lines in the spectrum of the inner corona and also is in conformity with the fact that there is no difference in color between the corona and sunlight, as was found at the 1932 eclipse.

But how are the dark lines in the outer corona to be explained? If the electron is to be the agent, then it is necessary to find some process whereby the random velocities of the electrons may be slowed down to such an extent that the Doppler effects will not obliterate the Fraunhofer lines. It is scarcely possible to assume a temperature in the middle corona less than 2,000° K. which would cause a Doppler effect of about 7 angstroms. We might, if we please, assume some (as yet) unknown influence from positrons, or that the sun's magnetic field, or some other unknown source, might gradually slow up the electron velocities at distances of 10′ from the sun's surface. If, indeed, there were a gradual slowing up of the electrons, this would cause the Fraunhofer lines to be broader in the inner corona and sharper in the outer corona, which is not in accord with the facts.

Under the assumption that the light of the corona is caused by the superposition of a continuous spectrum over a dark-line spectrum, it is necessary to conclude that electrons are present everywhere throughout the corona. As atoms and ions are present in the innermost corona causing the bright-line spectrum of coronium, it has been thought by many that ionized atoms must be the cause of the dark lines in the spectrum of the outer corona. If atoms were present in appreciable numbers, their existence would cause a Rayleigh scattering and a distribution of intensity in the coronal radiation different from that of the sun—which again is not in accord with the facts.

To explain the dark lines of the outer corona and with no change in color, Grotrian is forced to assume that the mechanism must be solid particles with diameters greater than three times the wave length of light. Close to the sun all solid particles would be immediately vaporized but at greater distances there would be an increasing number of solid particles; in fact, in the zodiacal light we have independent evidence of the existence of such material in interplanetary space. According to this hypothesis, within one radius of the sun's surface the electron is the scattering mechanism but farther out the interplanetary dust cloud does most of the scattering. If the dust cloud moves with the sun, then any details of coronal structure in the outer corona would persist for long periods without changes. For the long streamers which are prominent features of nearly every corona and which unquestionably change slowly with time, the dust cloud explanation is unsatisfactory. When knowledge progresses still further and we learn more about the physical laws that govern matter under solar conditions, then we may be able to find an explanation of the dark lines in the coronal spectrum that is simpler than the assumption of scattering of the sun's light by interplanetary dust.

Manifestly, for future progress we need more and better spectra of the dark lines in the coronal spectrum taken under clear skies devoid of water vapor in order to be more certain that the Fraunhofer lines are actually coronal in origin and do not come from sunlight scattered in the earth's atmosphere. We need more and better spectra of large dispersion in order to derive more accurate wave lengths of the bright-line spectrum by which to find the origin of coronium and to measure the rotation of the corona. Up to date we have pitifully few spectra of the corona with good definition and adequate dispersion. In the future these spectra must be measured photometrically to as great distances as possible from the sun's surface in at least two directions, at the sun's equator and poles. Needless to say, the photographs should cover as great a range in wave length as possible. More information is urgently needed concerning the degree of polarization of the coronal light to as great distances from the sun as possible.

In spite of the brilliant work of Lyot in photographing the corona outside an eclipse, it is not difficult to predict that coronal observations in the future as in the past will have to depend almost exclusively on the few precious moments of total eclipses which afford an average of 1 minute per year for accumulating observations.

THE FLASH SPECTRUM

Ever since it was first observed in 1870, the spectrum of the chromosphere continues to be one of the most important problems taken up for investigation at each succeeding eclipse. In spite of the enormous advances in instrumental equipment and technique, which in other branches of astronomy has appeared to accomplish almost the impossible, there are remarkably few good photographs of the flash spectrum. In fact, to check off on one's fingers the really first-class photographs taken by different observers at all the eclipses in the past 40 years, both hands would be unnecessary. The arch enemy of the eclipse astronomer, cloudy weather, has foiled many attempts, yet those that escaped the clouds have not obtained perfect results through poor focus or poor seeing or from inaccurate timing of the exposures.

At a total solar eclipse, the flash spectrum may be observed at the beginning and at the end of totality, either with or without slit, and by the use of prisms or grating. If without slit, the individual lines in the spectrum are a series of arcs of various intensities and of different lengths depending on the heights to which the solar gases extend above the sun's surface. The photographic plate may be fixed for each exposure or it may be moved gradually by an arrangement first tried out successfully by Campbell in 1905. A variation of the fixed plate is the "jumping film" successfully tried in 1932 by the Lick expedition. The principle is the same as with the movie camera, the film being moved between exposures made on a fixed film. The essential differences are that the camera is a spectrograph, the films are much larger in size than the standard 35-mm variety and the exposures and times for changing film may be each about ½ second in duration.

The fixed plate requires very exact timing of the exposures in order to obtain imprints from the most important layers of the chromosphere, those of lowest levels. The moving plate or the jumping film starts the exposures a half minute or more before the beginning of totality in order to catch the first flash so that the human element is partly eliminated. Each of the three methods has both its own peculiar advantage and at the same time its own disadvantages. Without here going into details, it is evident that on account of the very great difficulty of obtaining successful photographs of the chromospheric spectra already alluded to, it will be wise to utilize more than one type at an eclipse.

Astronomers do not go on an expedition merely to see the phenomenon and enjoy the beauties of the corona. Frequently the astronomer is in a dark room making exposures or he has such a large program to carry through that he can obtain merely a passing glimpse of the corona. Expeditions are to secure photographs which are measured and studied at home far distant from the few thrilling and excited moments of the total eclipse. In the year 1905 in Spain, the author obtained with an exposure of 2 seconds a photograph of the flash spectrum on which he has spent considerably more than 5 years of concentrated work.

Such a photograph is used to supplement researches being carried out daily on the sun without an eclipse by the use of a powerful spectrograph such as is attached to the 150-foot Mount Wilson tower telescope. From each line of the flash spectrum information is obtained in three separate and distinct directions: 1, wave lengths; 2, intensities; and 3, heights.

With the brief exposures available at eclipse time it is only possible to use a dispersion much smaller than that employed in daily solar work, with the result that the accuracy of wave-length determinations is not sufficiently high to ascertain systematic differences between eclipse wave lengths and those taken under ordinary solar conditions. Accordingly, chromospheric wave lengths can serve no other purpose than the identification of the lines from comparisons with Rowland's Tables in order to determine the gaseous element whence the spectral lines originate.

The most characteristic difference between the chromospheric and the ordinary solar spectrum is found in the relative intensities of the lines. In the eclipse spectra the helium lines, including D_3 discovered in 1868, are of great strength, whereas in the Fraunhofer spectrum they are entirely missing. In the eclipse spectra the hydrogen lines are of great prominence, and 32 lines of the Balmer series have been observed, whereas in the Fraunhofer spectrum only 4 hydrogen lines are observed. Compared side by side, the spectra on plate 7 seem to belong to stars of two different types rather than to the same object under different conditions.

A glance at the chromospheric spectra taken without slit shows that the strongest lines are of the greatest lengths on the photograph and hence the vapors extend to the greatest heights above the sun's surface. The heights from eclipse spectra in the capable hands of Saha provided him with indispensable information from which he was able to derive temperature and pressure conditions in the solar atmosphere. The theory of ionization developed a decade and a half ago as a result of heights from eclipse spectra has fairly revolutionized the science of astrophysics. Saha's theory has furnished an explanation of the causes of the differences in intensities of lines in spectra of stars of different types, has given a means of deriving the temperatures of the stars and has given measures of the distances of the stars by their spectroscopic parallaxes.

Starting out with Saha's theory, new information gleaned about the structure of the atom has revolutionized the method of attacking solar problems. Practically all the prominent lines in the spectrum of the sun have been assigned to multiplet groups with known excitation potentials measured in electron-volts, the arbitrary intensity scale of Rowland has been submitted to calibration tests which have revealed that the intensities depend on the number of atoms engaged in the formation of the spectral lines. From the weakest *Fe* lines perceptible in the solar spectra to the strongest, the number of atoms involved increases about 1,000,000 times.

A person having no knowledge of the theory underlying multiplet groups would not advance very far in the practical operation of correlating heights in the chromosphere with intensities either in sun or chromosphere before the fact would be forced upon his attention that generally the lines of greatest intensity reach the greatest heights, and moreover the intensities and heights for any element are greatest for the multiplets of lowest excitation potential. The best element for a study of these correlations is neutral iron. This element has been assiduously observed in the laboratory and very exact wave lengths are known. *Fe* is very rich in lines which have been grouped into multiplets with a wide range of excitation potentials.

From a study of 1,222 *Fe* lines in the flash spectrum the following facts were noted: (1) The strongest lines in the sun belong to the multiplets of lowest excitation potential; (2) with increase of excitation potential, the maximum intensity of lines in the multiplets steadily decreases; (3) for multiplets of any given excitation potential, there is a close correlation between intensities and heights; (4) for any given Rowland intensity, such as 6, the heights diminish as the excitation potentials are increased. There are many important consequences of these correlations.

Fascinating results on sunspots were announced by Evershed in 1909. With the slit of his spectrograph placed across the spot, he found that the wave lengths in the penumbra of the spots were different from the values at the center of the sun. The displacements which affected practically all lines were not constant but differed in amount depending on the intensities of the lines investigated, the shift being greater for the weaker than for the stronger lines. Evershed's results were abundantly confirmed at Mount Wilson with the result that conclusions are drawn that the displacements in wave length are a Doppler effect caused by the actual flow of the solar gases *out* of the spots at levels close to the sun's surface and *into* the spot vortex at higher levels. The heights from the flash spectrum furnish the explanation. As shown by St. John, the layers closest to the sun's surface have a motion of translation out of the spot at the rate of 2 kilometers per second. This motion becomes less and less in amount at greater and greater heights. At a certain level the outward motion ceases, while above this level the motion of translation is into the spots with increasing speeds at greater and greater heights above the photosphere. At the maximum heights reached by lines of the chromosphere, 14,000 kms by *H* and *K* of ionized *Ca*, there is a movement of the calcium vapor into the spot at the speed of 3.8 kilometers per second corresponding to a displacement of 0.063 angstroms.

The Evershed effect shows that there is a circulation of gaseous material in the neighborhood of sunspots. Other lines of research show that circulation is going on all over the sun. These motions cause Doppler shifts which affect exact wave lengths. In what follows some consequences will be noted, particularly as they are correlated with intensities and heights determined from eclipse spectra.

THE PRINCIPLE OF RELATIVITY

Einstein's theory of gravitation has been justly regarded as the greatest triumph of mathematical reasoning since the time of Newton. It is safe to say that no scientific achievement of recent years has aroused so much popular interest and enthusiasm as that evoked by the verification of the Einstein prediction by the 1919 total eclipse. In addition to the shift in star light by the gravitational pull of the sun amounting to $1''.72$ at the sun's edge, the principle of relativity has two other consequences shown by: (1) The motion of perihelion of the planet Mercury; and (2) the red shift of lines in the solar spectrum. We shall first take up the shift to longer wave lengths.

The Allegheny Observatory in cooperation with the Bureau of Standards has determined laboratory wave lengths of the highest degree of reliability. The method of obtaining the photographs was by a powerful grating spectrograph and interferometer, the wave lengths having an accuracy of 1 part in 5,000,000. For many reasons the results for neutral iron are more exact than for any of the elements. Wave lengths in the laboratory reduced to the conditions of vacuum pressure are referred to as "vacuum arc." Differences in wave length between the sun and the vacuum arc, after the greatest care is exercised to get all wave lengths to the one standard system, are given in the following table. From the differences, sun *minus* vacuum arc, are subtracted the predicted relativity shift amounting to $2.13 \times 10^{-6} \times \lambda$ where λ is the wave length in angstroms.

TABLE 1.—*Relativity shift in the sun*

Excitation potential	Intensity	Main diagonal			Side diagonal			Whole multiplet		
		No.	Δλ	Hgt.	No.	Δλ	Hgt.	No.	Δλ	Hgt.
0.07	6–40	9	+3.0	1,722	10	+1.4	1,300	19	+2.2	1,500
0.93	4–40	15	+2.0	1,157	20	+0.5	792	35	+1.2	948
1.54	2–30	12	+2.0	1,400	13	−0.1	823	25	+0.9	1,100
0.93	4–8	5	+1.2	540	6	−0.6	500	11	+0.2	518
2.2–2.8	3–10	10	+0.9	625	17	−1.0	500	27	−0.3	548
2.4–3.2	1–8	17	−0.9	497	25	−1.2	409	42	−1.1	445
2.2–2.8	1–6	27	−2.6	525	34	−2.5	518	61	−2.6	522
3.2–4.8	0–6	40	−2.9	406	49	−2.4	361	89	−2.6	381

The table takes account of all the *Fe* lines in well-defined multiplets. Altogether a total of 48 multiplets involving 309 lines were discussed, the material being divided into 3 series, strong, medium, and weak multiplets. In each case are given the number of lines involved, the height in kilometers from the flash spectrum and $\Delta\lambda$ (in units of 0.001 angstroms), which is the equivalent to the difference sun minus vacuum arc from which has been subtracted in each case the relativity shift.

From the abundant material that went into the table, it is evident that in addition to the relativity shift to the red, corresponding in the table to $\Delta\lambda=0$, there are other effects present. For the strong lines, those of small excitation potentials and greater heights, the value of $\Delta\lambda$ is positive while for the weak lines, those of higher excitation potentials and lesser heights, the values of $\Delta\lambda$ are essentially negative. The systematic differences between strong and weak lines is most readily explained as a Doppler shift caused by a circulation of vapors in the sun's atmosphere. On account of the higher temperatures and higher pressures near the photosphere, the solar activity causes the *Fe* atoms to ascend through the medium of thousands of weak lines of high excitation potential, the maximum velocity of ascent found for *Fe* being 0.2 km per second. The heights to which these atoms are ejected are much greater than can be measured by the lines in the flash spectrum. In the upper reaches of the chromosphere, especially where the pressures are minute, some of the atoms lose an external electron and become ionized.

From the law of nature that "whatever goes up must come down," the *Fe* atoms descend from the maximum heights. In their descent some of the ionized atoms gain an external electron and again become neutral. According to this interpretation, in a direct photograph of the sun showing its mottled surface the atoms ascending from the sun exhibit themselves over the small bright granules and the descending atoms over the large dark interspaces, the observed effect being an integrated one.

As an illustration of the correlations found to exist between different solar values, there are given in tabular form the quantities involved in the dozen lines of a composite multiplet of *Fe*. More than 100 times as many atoms are active in producing the strongest line at 3820 *A* as go to form the weakest one at 3940 A. The relativity shift amounts to 0.0082 A. Hence, within a single multiplet the heights found directly from the flash spectrum, or indirectly from the Evershed effect in sunspots, are not constant but are the greatest in size for those lines which involve the largest number of atoms.

Table 2.—*The Fe Multiplet* $a^5F-y^5D^\circ$

	F_5	F_4	F_3	F_2	F_1
D_4	3820 25 1600 0.000 0.0102	3887 8 800 0.005 0.0082	3940 4 500 0.016 0.0070		
D_3		3825 20 1500 0.000 0.0098	3878 10 1000 0.003 0.0090	3917 5 600 0.013 0.0074	
D_2			3834 14 1200 0.002 0.0094	3872 9 1000 0.003 0.0090	3898 5 600 0.013 0.0074
D_1				3840 10 1000 0.003 0.0090	3865 8 800 0.005 0.0082
D_0	Wave length Intensity in sun Height in kilometers Evershed effect in sunspots Sun minus vacuum arc in angstroms				3849 7 750 0.006 0.0078

RELATIVE DISTRIBUTION AND ABUNDANCE OF ELEMENTS IN THE LOWER CHROMOSPHERE

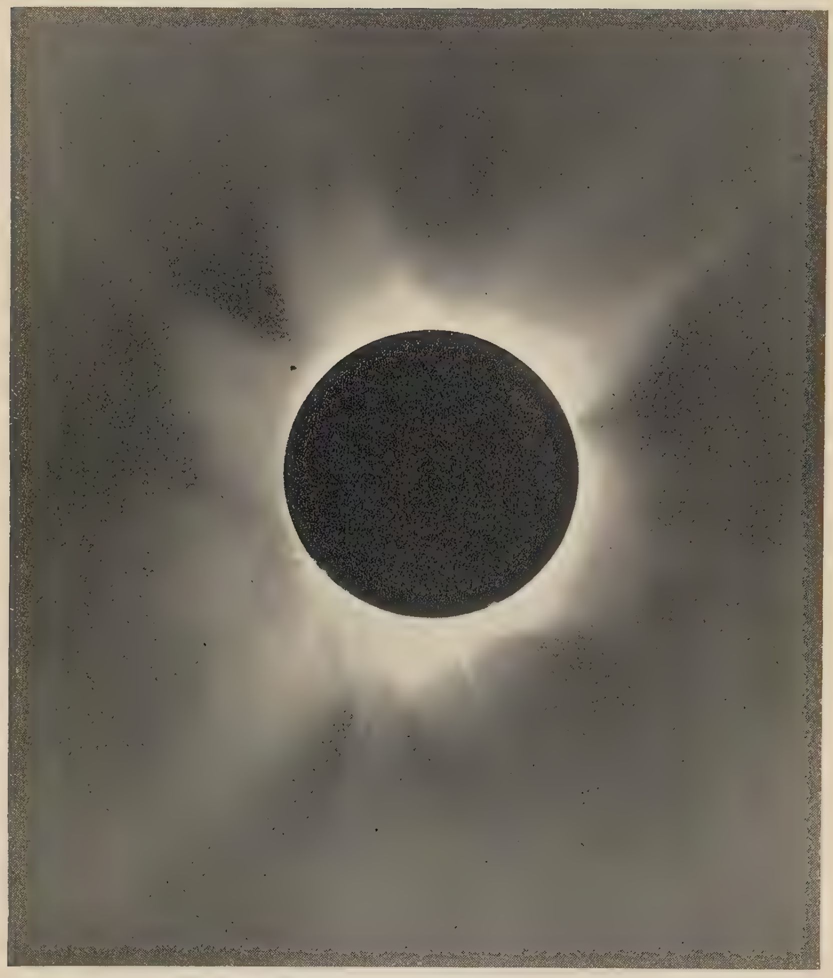
By combining the heights to which the various lines in a multiplet are observed in the flash spectrum with the multiplet intensity formulae, it has been possible to derive for many elements the density distribution in the lower chromosphere. This seems to indicate that turbulence and not selective radiation pressure is responsible for keeping the elements so well mixed. From the flash spectrum the relative abundance of various elements was determined and the results from the chromosphere were compared with those from the reversing layer, stellar atmospheres, earth's crust, and stony meteorites. It is inferred that within errors of observation the compositions of all samples are alike, with the exception that hydrogen is conspicuously deficient in the earth's crust and in meteorites and is probably more abundant in the chromosphere than in the reversing layer. It seems also safe to conclude that there is a marked deficiency of the heavier elements in the chromosphere.

RELATIVITY SHIFT OF STAR IMAGES

At the 1929 eclipse, the Potsdam party using two different cameras found the Einstein deflection reduced to the sun's edge to be 2″.24 ± 0″.10, a result which differed radically from the Lick deflection 1″.75 ± 0″.09 at the 1922 eclipse, or from the theoretical value of 1″.72. Unfortunately, at the 1929 eclipse, the bright stars photographed on the eclipse plates were extremely unsymmetrically placed. A straight line passed through the center of the sun found 17 stars on one side and a single star on the other side of the line. As a consequence, the light deflections to be determined depend to a high degree on the plate constants used in the reductions. If, by means of least squares, the scale correction is determined at the same time as the other constants of the plate from the star observations themselves, that is, by following the procedure adopted in 1919 and 1922, the 1929 plates give a deflection of $1''.75 \pm 0''.13$. Taking the values of all eclipses together as solved by least squares, the observed value of the relativity deflection is $1''.79 \pm 0''.06$.

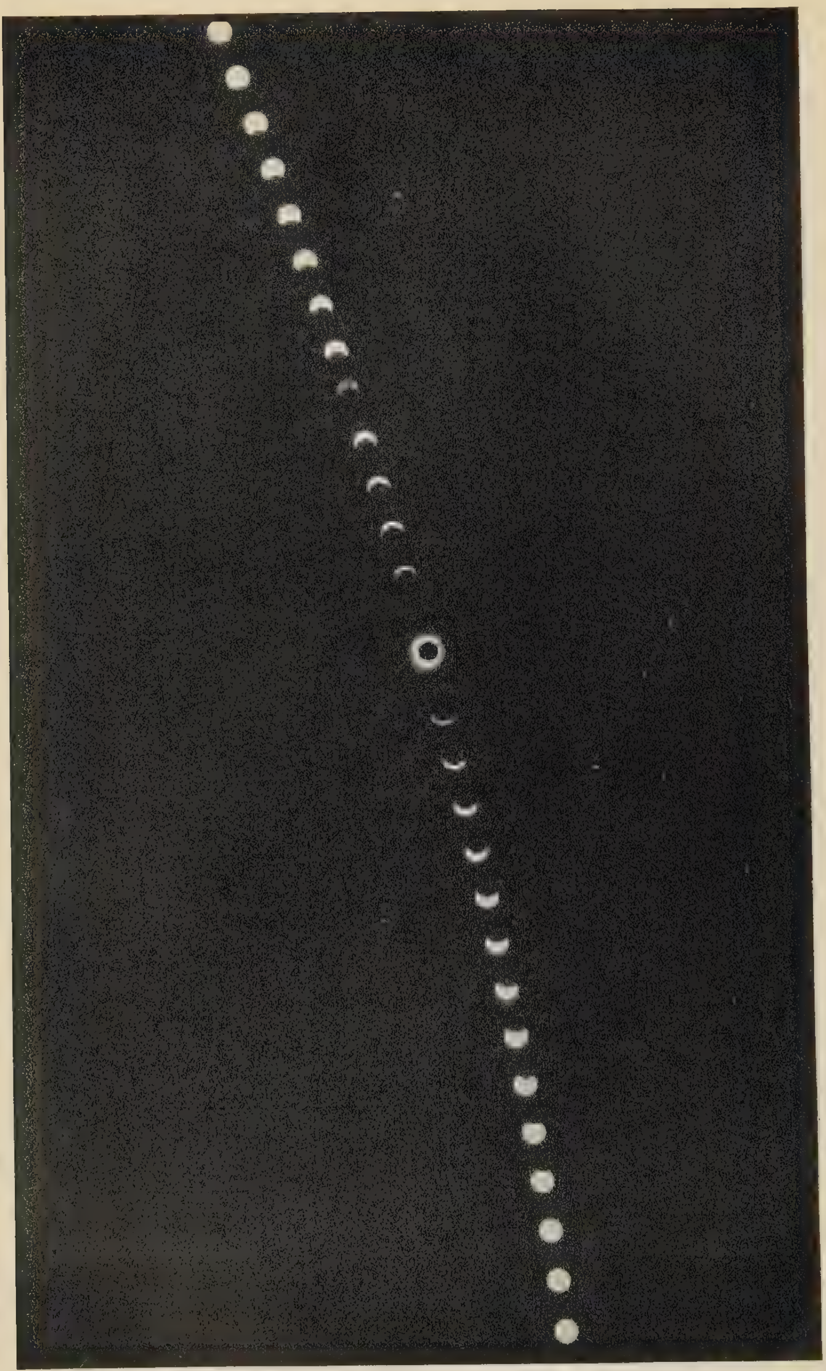
The differences between the various reductions of the 1929 eclipse show the underlying difficulty of the whole problem, namely, the practical impossibility of adequately separating the scale of the plates from the star deflections. It, therefore, appears evident that work on relativity displacements must be repeated at future eclipses by processes which will insure a far greater accuracy than has been attained in the past. Such a recommendation is quite obvious—but unfortunately it will be quite impossible to put this recommendation into effect at any time within the next two decades on account of the poverty of stars in eclipse fields.

Most astronomers and physicists are now satisfied that the theory of relativity has been verified by observations made in three different fields of investigation: (1) The motion of the perihelion of Mercury; (2) the red shifts of lines in the solar spectrum; and (3) deflections on eclipse photographs. In addition, Adams has measured a very large relativity shift in the system of Sirius, and Trumpler has measured red shifts in stars of *O* type. Many new and interesting facts concerning this theory will be accumulated in the next quarter of a century of progress before there is another eclipse with a satisfactory distribution of bright stars that will permit another thorough test of the relativity displacement.



THE CORONA, JUNE 8, 1937.

Photographed at the National Geographic Society-U. S. Navy expedition to Canton Island by I. C. Gardner.

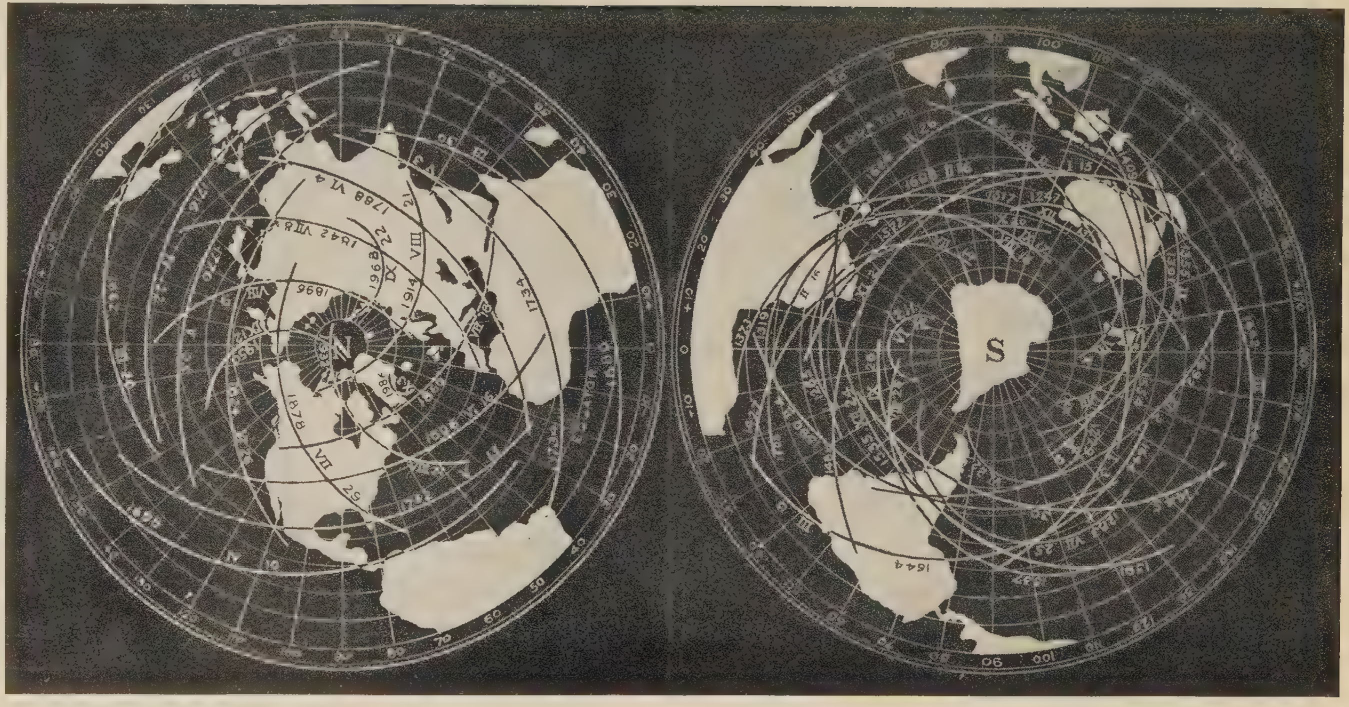


National Geographic Society

Photograph by R. H. Stewart

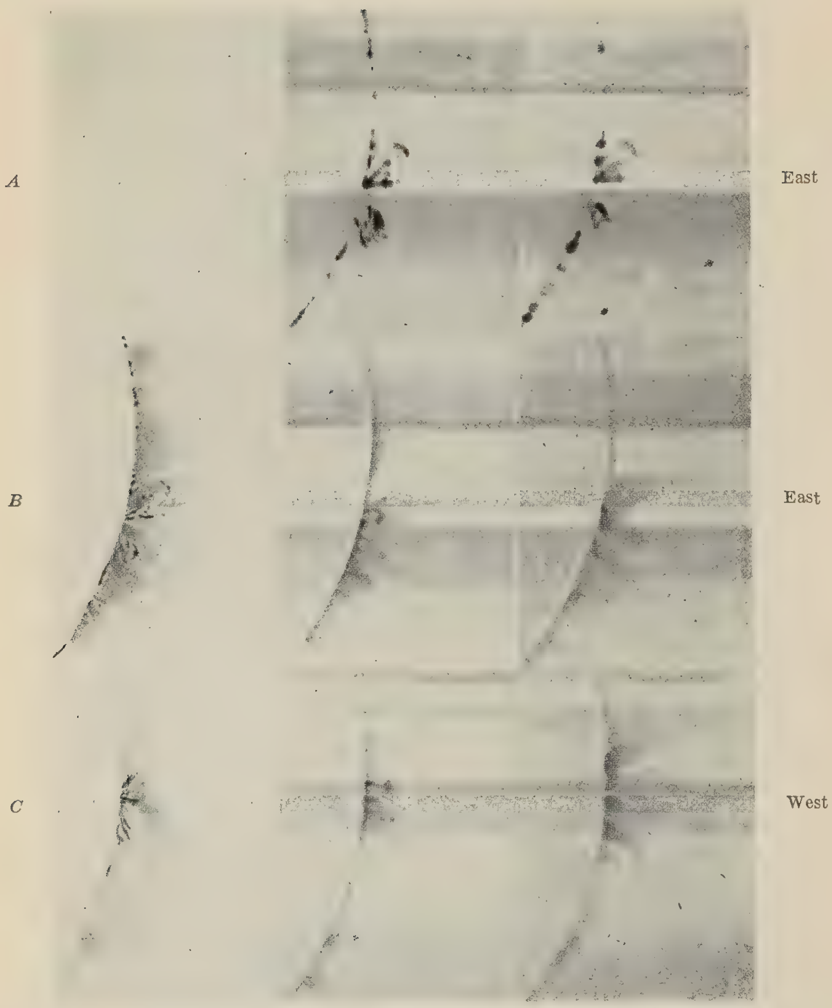
THE PROGRESS OF THE 1937 ECLIPSE.

Exposures were made every 5 minutes from first contact (bottom). Note that in the 26 exposures that extended over more than 2 hours only one, the fifth after totality was over, was made through thin clouds.


N
1734
1788 VI 4
1842 VII 8
1896
1914
VIII
21
1968
IX
22
1984
1878
VII
25
S
1644
1319
1373
II 16

A SERIES OF 44 TOTAL ECLIPSES BEGINNING NEAR THE SOUTH POLE JULY 12, 1211, AND ENDING OCTOBER 3, 1986, NEAR THE NORTH POLE.

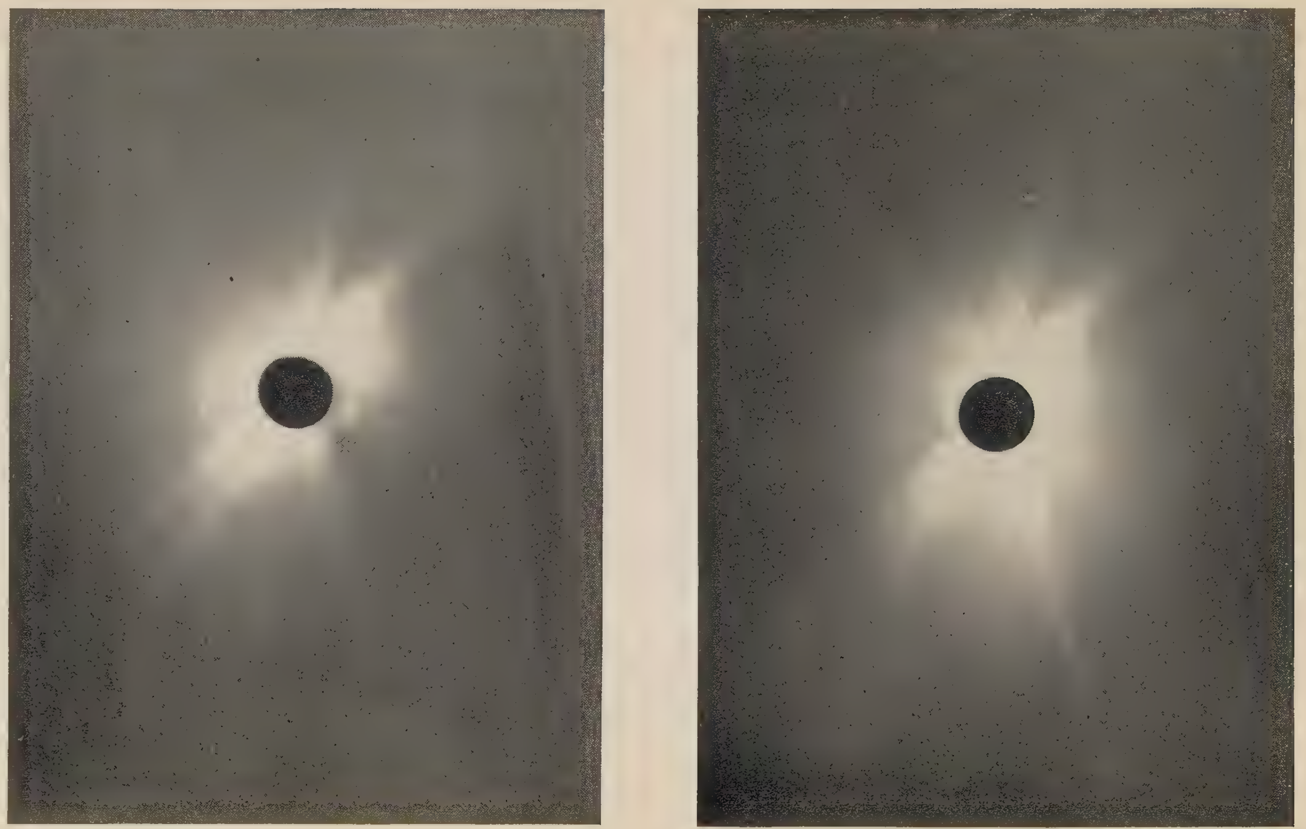
The eclipse of August 31, 1932, belonged to this series



ECLIPSE SPECTRA IN 1930 PHOTOGRAPHED BY CONCAVE GRATING WITHOUT SLIT.

A and *B* refer to the same eastern portion of the sun. For purposes of comparison the positions in *C* at the western edge of the sun are inverted.

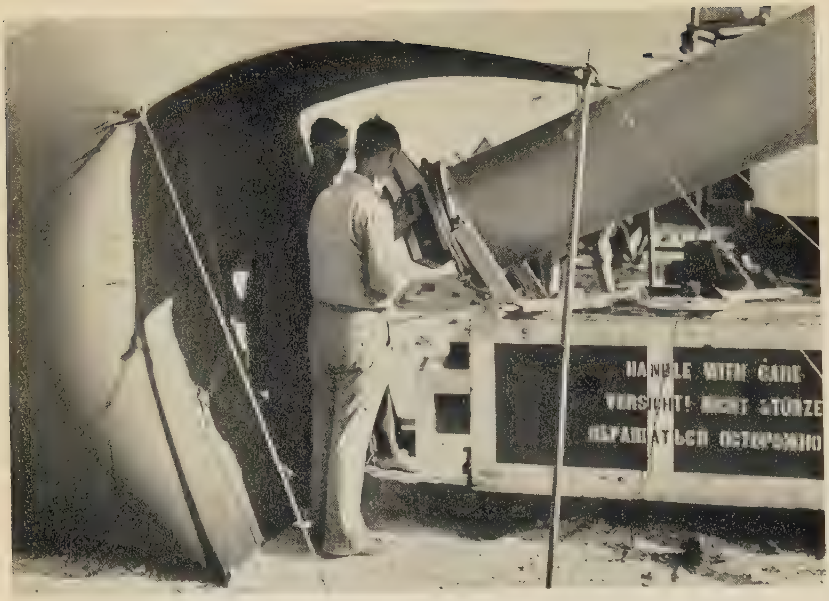
In *A* are given the *K* line and the *H*α line, both from the chromosphere. In *B* and *C* are given (from left to right) details from direct photographs of the corona near the beginning (*B*) and the end (*C*) of totality, and the structure in the coronal rings at wave lengths 5303 and 6374, respectively.



National Geographic Society Photographs by F. K. Richtmyer

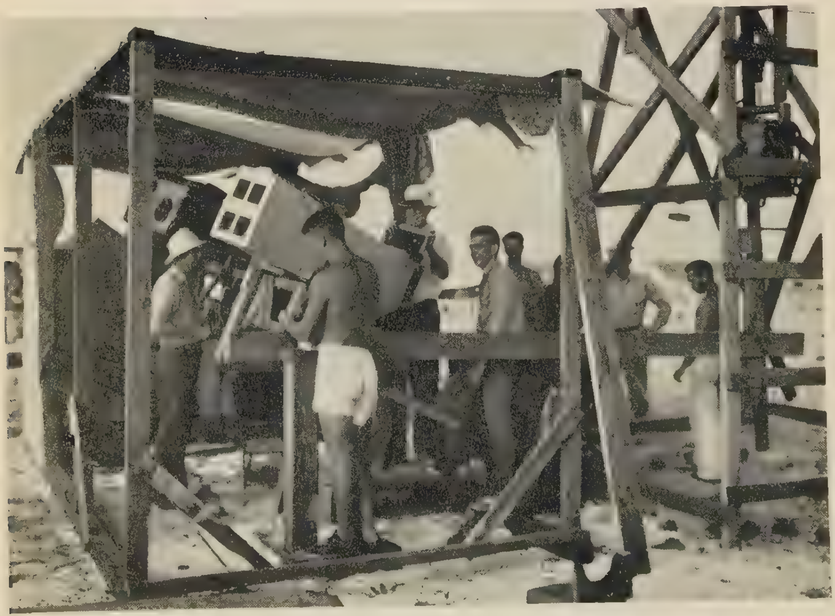
SIMULTANEOUS PHOTOGRAPHS WITH IDENTICAL LENSES BUT WITH SCREENS OF "POLAROID" TURNED AT DIFFERENT ANGLES.

From these photographs the percentage of polarized light at various distances out from the sun can be measured. On the right photograph one coronal streamer of the 1937 eclipse extended to 5,000,000 miles from the sun's surface.



HANDLE WITH CARE
VORSICHT! NICHT STURZE

1



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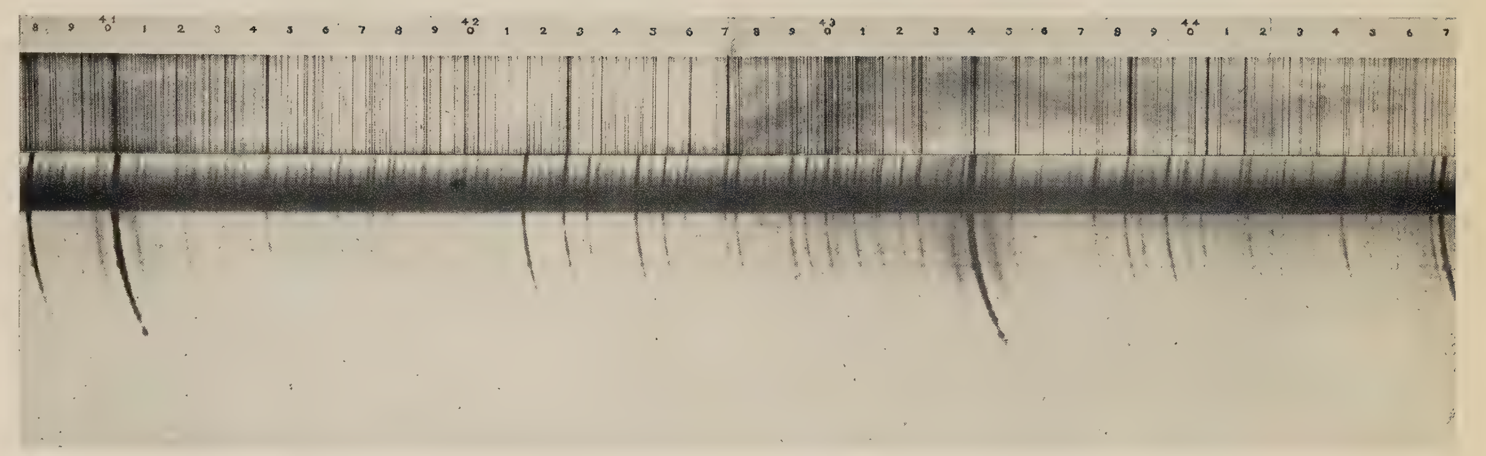
2

REHEARSALS FOR THE 1937 TOTAL ECLIPSE.

1. The camera that took the photograph of the corona on plate 1. 2. F. K. Richtmyer and his helpers.


8 9 41 0 1 2 3 4 5 6 7 8 9 42 0 1 2 3 4 5 6 7 8 9 43 0 1 2 3 4 5 6 7 8 9 44 0 1 2 3 4 5 6 7

Comparison of Fraunhofer and 1905 Chromospheric Spectra.

Top: Wave length scale. *Middle:* Rowland's Atlas reduced. *Bottom:* Negative from eclipse enlarged.

Note the greater intensities in the spectrum of the chromosphere of the enhanced lines at the following wave lengths: 4077 (Sr), 4215 (Sr), 4233 (Fe), 4247 (Sc), and 4443 (Ti). The hydrogen lines at 4101 and 4340 are much stronger in the chromosphere and the strong helium line 4471 is absent in the sun.

1

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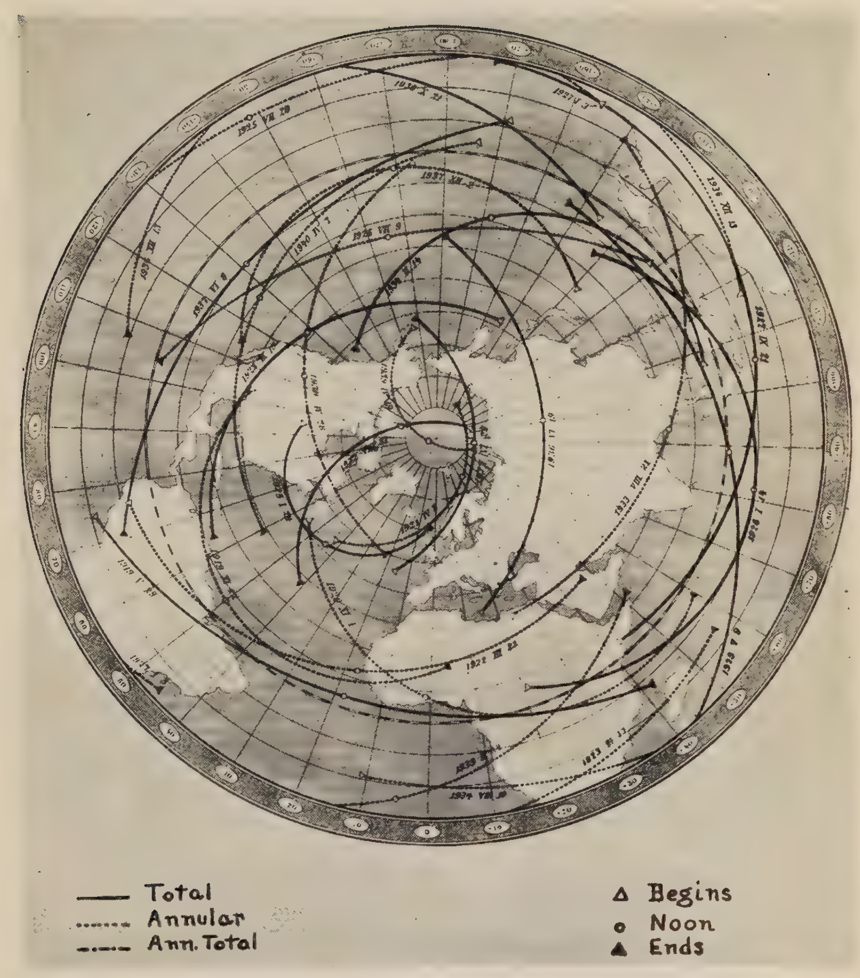
2

ADJUSTING SPECTROGRAPHS FOR THE 1937 ECLIPSE.

1. Theodore Dunham, Jr., and Charles G. Thompson. 2. S. A. Mitchell putting into line a concave grating spectrograph.


Total
Annular
Ann. Total
△ Begins
○ Noon
▲ Ends

TRACKS OF SOLAR ECLIPSES BETWEEN THE YEARS 1919 AND 1940.

CHANGES IN THE LENGTH OF THE DAY

By Ernest W. Brown
Yale Observatory

Even to the professional astronomer it comes perhaps as a shock when he first learns that the moon must be regarded as our ultimate exact measure of time. He is so accustomed to the apparent vagaries of its motion, to seeing it all over the sky and to being bothered by its presence that it is difficult to realize the exactness with which every detail of its motion can be followed. On the other hand, the stars follow a regular and nearly uniform motion due to the rotation of the earth, so that the latter seems to be the natural standard. He knows, of course, that the length of the day is very slowly increasing because the friction caused by the tides is slowing down the rotating earth, but he knows that its amount is very small and supposes that it is known.

However, our observational knowledge of this gradual increase in the length of the day comes chiefly from the moon, because it depends almost entirely on the study of ancient eclipses of the sun by the moon. The place of occurrence of these eclipses is not the same as calculation shows it should be if the revolving earth had maintained its rate. The earth moves so fast on its axis that if the moon is not at the appointed place at the given moment the earth can slip round an appreciable amount before the meeting with the sun occurs, so that a total obscuration occurs elsewhere than in the place predicted. The same thing occurs if the earth has been going round more slowly than the calculated value.

Several workers have examined these old records. The question is not a simple one, chiefly because the historians who wrote them were not expert in observing the phenomena or in gathering the particular kind of information that is needed by the astronomer. We have to judge from the details which may be given that the all-important question whether the eclipse was seen as total or partial is properly answered. The latest and, I think, the best of all these investigations was made by Dr. J. K. Fotheringham, of Oxford, England, who died recently. Dr. Fotheringham was a notable classical scholar who knew the languages in which the accounts were originally written and the habits of thought and expression of the men who wrote them, and so was able to appraise with some degree of certainty the real meanings of the phrases which they used. He became interested in the astronomical side of the records and took the trouble to learn how to deal with them according to the best canons of the astronomer. He became thoroughly expert in this part of the work, and the combination of knowledge and judgment which he gave to it has produced excellent results.

Some years ago Prof. G. I. Taylor added to our stock of information by showing that the greater part of the friction came from the tides in shallow seas. He calculated that the Irish Sea alone produced about one-fiftieth of the necessary amount. A little later Dr. Jeffreys made a similar survey of the whole earth. He found, though his calculations were necessarily rather rough because only rough data were available, that the total amount was about the same as that given by observation. One interesting fact emerged, namely, that the Bering Sea contributed the greater part of it. Had better data for that stretch been available he would have been able to make his calculations much more exactly.

This result of Jeffreys raises a point which is sometimes forgotten, namely, that the present figure for the amount of the friction, and consequently for the slowing down of the earth, may have no great degree of permanence. The southern boundary of the Bering Sea is a highly volcanic region in which changes are continually taking place. It requires no great stretch of the imagination to suppose that in the course of a few thousand years the depth of this sea and its boundary may materially change and that in consequence, changes will occur in the amount of the friction. Thus caution is needed when we use the present figure for arguments concerning the past and future history of the earth-moon system—a question I shall deal with briefly below.

The amount of this gradual change is very small—the day is longer now by less than one thousandth of a second than it was a century ago. The error of the clock increases much faster—in fact, as the square of the elapsed time. If the clock loses 1 second in a century it will lose 100 seconds in 10 centuries, and in 100 seconds the earth, in the middle north or south latitudes, turns a good many miles. This is why the place of an ancient total eclipse is so sensitive to small changes in the length of the day.

Of much more scientific importance is the change in the moon's motion. As the earth is losing energy, the moon, which is responsible for the greater part of the change because of the fact that it is the chief tide raiser, must be gaining energy. This makes it move around the earth more slowly and sends it farther away from us. If this went on indefinitely the moon would leave us. But it is calculated that when the month is about twice as long as at the present time it will stop receding. What will happen afterward is largely a matter of speculation.

Much more startling are changes which seem to be irregular and which take place in a much shorter time. Our knowledge of them arose originally from a discovery by Simon Newcomb that there was an apparent oscillation in the motion of the moon which was not accounted for by theory. I have said above that the theory of the motion of the moon is the most accurate amongst those of all astronomical bodies. But this has been achieved only at the cost of great labor. Starting with Isaac Newton who formulated the laws of motion and gravitation from which the theory is developed, a host of workers have toiled to improve it—Euler, Laplace, Hansen, Delaunay, Newcomb, and G. W. Hill, to mention only a few of the most famous great mathematicians and great astronomers who have added successively to it. Finally, the writer, building on the work of his predecessors and especially on that of G. W. Hill, gave the results of a calculation which, if free from mistakes, had an accuracy at least comparable with that of observation. This last work had to be done by old-fashioned methods since machines were not then available and the human factor entered largely. To make assurance doubly sure, the work is being repeated almost wholly by machinery so that little doubt will remain as to the accuracy of the results.

At the time of Newcomb's discovery, however, the best theory was that of Hansen, and it was by no means certain that some important term had not been omitted which could account for the deviation. The completion of the writer's theory showed that such a solution of the difficulty was highly improbable since the deviation was much larger than any probable mistake in the theory.

The question of the source of the deviation was reopened by Innes, who, in examining the deviations of the planet Mercury, found characteristics which with some stretching of the imagination could be compared with those given by the moon. But the observational material was too poor to carry conviction. However, it suggested to the writer the thought that perhaps another body, the sun, might show changes more certainly than Mercury. The sun moves much more slowly around the earth than Mercury does around the sun and on that account is a much poorer testing body. On the other hand, it has been continuously and carefully observed at every fine noon for 170 years and perhaps the mass of observations could make up for the slow motion.

The material was gathered and the curves of deviations from its theoretical orbit drawn, and it was immediately seen that the question had been solved—the deviation was not in the motion of the moon but in our measure of time. Newcomb had suggested this as a possibility, and Innes had adopted it to explain his deviations.

I must go into some further details in order to show what the evidence is worth. Newcomb had represented the deviations of the moon on a scale which was wide horizontally and narrow vertically. In order to get the material on a smaller piece of paper, I altered the horizontal scale so that the horizontal scale for a century was about the same as the vertical. A peculiar feature appeared. The curve was not like an ordinary sine curve, which has flat tops and bottoms and which is characteristic of motions produced by continuous forces. It had sharp pointed tops and bottoms and was much more like a series of intersecting straight lines than a continuously changing curve. In other words the changes that took place were comparatively sudden and then stopped, as if an occasional blow had been given.

I had three of these sudden changes which were large: One about 1790, which, however, might have been gradual, as the observations are not very accurate; one about 1897; and a third about 1917. Since the last one there has been no further large change. The last change disposes of Newcomb's sine curve—it will not fit at all. When the sun curve was compared, it showed the same features as the moon curve and in particular the three sudden changes of direction at the same times. There could then hardly be any doubt about the source of the deviations.

Other workers have added informative evidence from the planets Venus and Mars. DeSitter gathered all the evidence from various sources including some from the other satellites and in general showed that the result was correct. But there was a fly in the ointment, as usually happens in pioneer scientific work. Although the changes in rate shown by all the bodies occurred at the same dates, the amounts of the changes shown by the sun and planets were less than those shown by the moon in the ratio 1.28 : 1. DeSitter estimated the probable error of this factor to be ±.08 so that it is probably real and not a mere effect of inaccurate observations. This factor, if real, indicates that the moon has something to do with the changes but has only a small effect.

The amounts of these changes in the rate of the earth's rotation are considerable from the astronomical point of view. The greatest of which we have any certain knowledge is that which occurred about 1897 and which changed the apparent length of the year by a second. This is getting near the best that the new Shortt clocks can show, but the latter have not yet quite attained the accuracy which is needed for the purpose. Perhaps if we had a dozen such clocks, kept going under the very best conditions, we might, by averaging the times they would show, detect such a change. There is some interest in this question at the present time because the deviation of the earth from showing correct time is now greater than it has ever been since observations were made with sufficient accuracy, and consequently it is reasonable to expect that a new change may soon occur.

It is natural to ask at this stage how the observations of the moon are made and the nature of the errors to which they are subject.

The fundamental series have been the meridian observations at Greenwich and Washington—in the former case an unbroken series since 1750. In these observations the times at which the limb of the moon crosses the wire in the transit meridian telescope is observed. The declination is also noted by placing the cross-wire on the upper or lower limb of the moon. By means of tables, given in the nautical almanac, the position of the moon at those instants can be found. Unfortunately, these observations are subject to many errors. There are the instrumental errors, most of which can be dealt with; the errors due to the irregular shape of the limb, for which corrections can be made; and finally the error of the observer when he tries to make the wire tangent to the limb. The last is the most serious because it varies with different observers and with the same observer at different times. About 100 observations a year are obtained in this way at each observatory with some 50 more at Greenwich obtained by noting when the wires cross the crater Mösting A. During the last 12 years a campaign has been under way to obtain and utilize occultations. Here we simply observe the instant when the moon covers a star. There are practically no instrumental errors, and as the time of occurrence need only be observed to the nearest second, the human factor does not seriously enter. But they still depend on the shape of the edge of the moon and, in addition, on the accuracy of the places of the stars. Both of these errors can be largely corrected so that the possibility for accuracy with this latter method seems to be greater than with the meridian observations. It has been possible also to obtain many more such observations. During the 3 years 1933–35, we had an average of over 1,400 a year. With all this material we now know with considerable accuracy how the rate of rotation of the earth is varying from year to year. It should be mentioned that Newcomb got his original curve from occultations which he gathered from all over the world.

What is the cause of these variations in the earth's rate of rotation? At present the answer is—we do not know. But the facts at our disposal enable us to eliminate a good many hypotheses that might otherwise have some plausibility and thus narrow the field of conjecture. Perhaps we may even go so far as to say that possibly we can obtain new information concerning the behavior of our earth.

The quantity we are mainly concerned with is the angular momentum. This is a product of the angular velocity, the mass, the square of the radius, and a constant which depends on the manner in which the mass of the earth is distributed. Theory tells us that this cannot be changed (except in a manner which is easily calculated and which is allowed for). We have seen that there is one important exception, namely, the frictional effect of the tides produced by the sun and the moon. The irregular changes might be supposed to be due to variations of the frictional effect. But the changes we are considering are enormously greater than the whole frictional effect and consequently any variation in the latter is quite powerless to produce them. Indeed theory goes a step farther and indicates that no force external to the earth that we know of can produce a change in the angular momentum, except in the manner just stated.

We are thus reduced to asking whether there are any external forces which can alter the distribution of matter in the earth. The only such forces we know of are tidal actions by the sun and moon. But such forces are quite regular in their action, and the changes we observe are extremely irregular, so that this source must be ruled out. There are in fact no known forces outside the earth that can produce the observed results.

Are there surface changes due to meteorological causes or other conditions which might be effective? When these results were first published it was suggested that accumulations of ice and snow at the poles might account for the phenomena. But calculation shows that in order to use this source, the requisite amount of frozen water would change the average sea level all over the world by something like a foot, and we should all know if this had happened in 1897. I took the trouble to look up the records and, as I expected, found no significant change in sea level near that date.

Local changes of level or volcanic action are apparently far too small to produce the required effect. DeSitter calculated that if the whole group of the Himalaya Mountains could be razed and placed at the poles, it would produce only a fraction of what is needed. No imaginable surface changes seem sufficient for our purpose.

We are then driven to changes below the surface to account for it. Here we must resort entirely to hypothesis, for there is nothing that we actually know which is available for our purpose. The most plausible start is to imagine some action which changes the radius of the earth. The astronomer has already adopted some such idea to explain the changes which take place in the light of certain variable stars. He imagines that they pulsate bodily—perhaps it is a feature of all stars to a greater or lesser degree. If so, there is no difficulty in imagining a pulsating earth—the remnant perhaps of a time when such changes were on a large scale. The amounts required seem quite small. If there is a uniform dilatation and compression throughout the whole mass of the earth, a change in the external radius of 5 inches is sufficient to account for the maximum change of rate which has so far been observed. If the change took place in a layer 50 miles below the surface, the external radius would have to change by 12 feet to produce the same effect. If a change of this character is the cause of the phenomenon, something between these two extremes is indicated. Another suggestion which has been made is the redistribution of matter inside the earth, different densities playing the principal role in this hypothesis. I repeat, however, that these are mere hypotheses made to account for the phenomenon.

My own idea is to imagine the existence of a layer of material not too far from the surface which is at or near a critical temperature, the latter being defined as one in which a small change of temperature produces a relatively large change of volume. There are many substances which possess this property. Thus a small change in the interior condition of the earth might easily produce a relatively large change in the volume of the layer, causing necessary expansion or contraction at the only portion which is free to move, namely, that above the layer.

A change of volume considerably less than 1 percent in a layer with a thickness of a mile would be amply sufficient to take care of the maximum observed change. Incidentally, it may be noted that the change in volume consequent on any change in temperature gives a rapid method of transfer of heat in a mass composed of different materials, for changes of pressure are transferred without delay and the cooling of a hot mass could be made much more rapid in this way than by mere conduction.

The hypothesis gives a mechanism for mountain building which has some rather attractive features. The elasticity of the surface materials of the earth is amply sufficient to take care of any such increase in the volume of its crust. As a matter of fact, however, the surface is broken and fissured in all directions, and the effect of an expansion would be to open these fissures. They would be partially filled by matter dropping from above or pressed in from below. In any case, when the subsequent contraction came, they would not be able to close and there would necessarily be a bulging toward the surface. The evidence we have indicates that the major changes take place at intervals of the order of a century or less, so that the same fissures are likely to repeat their successive openings and closings, resulting in successive elevations of the same region. The energy necessary for the process is thus traced back to the interior heat of the earth and the supply would seem to be ample.

It is not entirely impossible that the hypothesis could be tested if and when the next great change occurs. Some device which could measure very small changes in the opening of a fissure could certainly be set up. If one costing a small sum only could be constructed and numbers of them placed in various parts of the earth, especially in those regions where mountain building is known to be going on, the information needed could be obtained. In a few places elaborate mechanisms with recording devices might be employed. In any case, much might be learned concerning the movements which are continually taking place on the surface of the earth.

THE THUNDERSTORM [1]

By E. A. Evans and K. B. McEachron
Pittsfield Works, General Electric Co.

[With two plates]

In this article the writers have attempted to gather together in one place sufficient information on the electrification of thunderclouds, the causes of their formation, and their characteristics, to give engineers a general understanding of the thunderstorm. To this end the writers have drawn on their own personal experiences in field studies of lightning and have selected and interpreted the ideas of a number of investigators who have presented their findings in numerous publications, many of which are not easily accessible to the average engineer. In a number of instances, additional field data have been added to round out or corroborate the findings and deductions of previous investigators. The characteristics of actual thunderstorms are described to amplify the conceptions obtained from descriptions of "ideal" models which, for ease in understanding their operation, necessarily have to be simple. Finally, an explanation is given as to how a knowledge of the characteristics of thunderstorms and of the factors affecting their formation and travel can be applied in lightning protection problems.

ELECTRICAL PICTURE OF THE THUNDERSTORM

It is desirable first to review briefly the operation of the thundercloud generator before explaining its formation and characteristics. As a helpful picture of this generator, the lower part of a thundercloud can be visualized as one plate of a physically huge condenser, the air as the dielectric, and the ground, or another part of the cloud, as the other plate. It must not be forgotten that the cloud is not a conductor but consists of a multitude of poorly conducting water droplets suspended in an insulating medium, the air. The charge of the cloud is not distributed on its surface as on the plates of a metallic condenser, but is a volume charge distributed on water droplets and air ions throughout considerable regions in the cloud.

The cloud charge attracts to the ground beneath and near it an equal amount of charge of opposite sign. Between the charge on the cloud and the charge on the ground an electrical field exists just as between the charges on the plates of any other condenser. This field increases as the generation process goes on within the cloud. When the field reaches a certain critical value a discharge between cloud and earth takes place.

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[1] Reprinted by permission from the General Electric Review, September 1936.

HOW THUNDERCLOUDS BECOME ELECTRIFIED

It is certain that the electrification of thunderclouds is closely connected with the turbulent convection systems which form them. This was very evident during an intensive 2-year field study[2] of thunderstorms made from a mountain top in Colorado by one of the writers of this article. In the course of some 300 storms there were numerous occasions when the shape and nature of the storm cloud and its electrical activity were plainly visible at the same time. Clouds with dense well-developed heads, showing evidence of violent internal convection systems through many and continually changing surface protuberances, were practically always active electrically. On the other hand, clouds which did not indicate the presence of such convection systems were not electrically active.

The exact manner in which these convection currents take part in the electrification of thunderclouds is not completely known. That they separate the small raindrops and cloud particles from the large raindrops, and that by doing so they separate positive and negative electricity within the cloud, is generally agreed. But whether they cause the electrification of the raindrops by breaking them up, or by bringing them into contact with each other while they are polarized and then separating them again, or by helping to bring positive and negative air ions in contact with polarized raindrops, is a controversial subject. The three best known theories of thundercloud electrification, each involving one of the foregoing methods of electrification, will now be described.

SIMPSON'S BREAKING-DROP THEORY

Simpson's[3] [4] breaking-drop theory of thundercloud electrification is probably the best known and most generally accepted. In this theory, a major role is played by violent upward air currents, which, for reasons to be explained later in the section on "Causes of Thunderstorm Formation", exist in active thunderstorms. These upward air currents carry up moisture which condenses as it rises. The condensing water vapor combines into drops. When these attain a size and weight such that the force of gravity can cause them to move against the rising air currents, they fall. Joining with other drops as they fall, they grow larger and an increasingly greater number of them are broken up by the action of the upward air currents. The largest drops finally approach a limiting size, which according to Lenard [5] is about half a centimeter in diameter. Drops larger than this are unstable and soon break up into many small droplets surrounding a rather large center drop.

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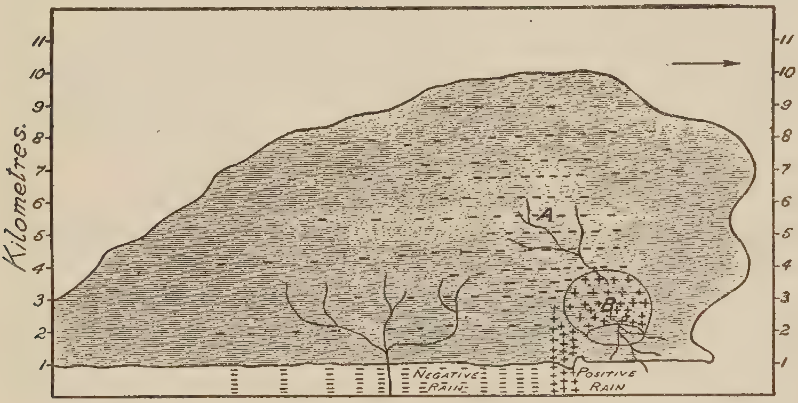
[2] Evans, E. A., A study of the mechanism of the lightning discharge, Stanford Univ. thesis, October 1932.

[3] Simpson, G. C., Electricity of rain and its origin in thunderstorms, Phil. Trans. Roy. Soc., ser. A, vol. 209, pp. 379-413, 1909.

[4] Simpson, G. C., The mechanism of a thunderstorm, Proc. Roy. Soc., ser. A, vol. 114, pp. 376-401, 1927.

In the breaking of rain drops lies the electrification process of thunderstorms according to Simpson, for he believes (and has advanced laboratory experiments supporting his belief) that, when the drops break, negative ions are released into the air while the water drops become positively charged. The negative ions joining with minute cloud particles are carried upward at the velocity of the air currents and are thus quickly removed from the vicinity of the positively charged rain drops. The rain drops are also carried upward but at a slower rate until by recombination they again become large enough to fall. In falling they continue to grow until they break up again. This liberates more negative ions into the air and leaves a higher positive charge on the rain drops.



Royal Society of London.

Figure 1.—Distribution of electrical charge in a heat thunderstorm. (After Simpson.)

So the electrification process goes on. More and more negative ions are liberated and transported to the upper and rear regions of the thunderstorm. The rain drops acquire a higher and higher positive charge and accumulate in the lower part of the cloud in a restricted region. The location of this region is determined by the velocity of the upward air currents; for, since the largest drop which can exist can be supported by an air column moving upward at a velocity of 8 meters per second, no rain can fall through regions where the air movement is equal to or greater than that velocity.

Thus Simpson arrives at the thunderstorm model reproduced in figure 1. In this diagram, positively charged water drops accumulate in region *B* above the region where air velocities are 8 meters per second or more (indicated in the illustration by an ellipse at the base of region *B*). The negative charge is distributed as shown over a much larger region of the cloud in the upper part and throughout most of the body of the cloud.

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[5] Lenard, P., Ueber Regen, Meteorol. Zeitschr., vol. 21, p. 249, 1904.

Simpson's measurements of the charge on rain drops are in agreement with his conception in that they show that as storm clouds pass overhead the falling rain consists first of large drops charged positively; next of a mixture of negatively charged and positively charged rain; and, finally, a steady downfall of moderate to small-sized negatively charged drops.

ELSTER AND GEITEL'S INFLUENCE THEORY

Elster and Geitel[6] [7] have postulated a very different theory of cloud electrification, in which the upward air currents of thunderstorms play as prominent a part as in Simpson's theory. In arriving at an understanding of their theory, one can visualize the carrying up of atmospheric moisture by the upward air currents, the formation of drops, their combination and their fall much as described in Simpson's theory. Since the earth is normally negatively charged, a separation of electricity will occur on each water drop by induction even though it is remote from the earth. The bottom of the drop will be positively charged and the top negatively charged. As the large drops fall through the upward moving air stream, smaller drops being carried upward come in contact with the lower surface of the large drops. As the negative top of each droplet contacts the positive bottom of a larger drop, an exchange of charge occurs. The smaller droplet gains a positive charge while losing an equal amount of negative charge to the larger drop. The smaller drops continue their upward journey gaining positive charge at each contact while the larger drops proceed downward gaining negative charge as they go. Thus an accumulation of negative charge occurs near the bottom of the cloud while the upper region becomes positively charged. This theory is of interest in view of the fast-accumulating evidence[8] that a very large majority of the discharges to transmission lines are from negatively charged clouds.

C. T. R. WILSON'S THEORY

C. T. R. Wilson[9] [10] has suggested still another theory of thundercloud electrification. He explains his theory by following the progress of the water drops through the rising air currents of the thunderstorm and attributes their electrification to contact with air ions.

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[6] Elster and Geitel, Bemerkungen Ueber den Electrischen Vorgang in den Gewitterwolken, Wied. Ann., vol. 25, p. 116, 1885.

[7] Geitel, H., On the origin of precipitation electricity, Physik. Zeitschr., vol. 17, p. 455, 1916.

[8] Lewis, W. W., and Foust, C. M., Lightning investigation on transmission lines: V, Amer. Inst. Elec. Eng. Trans., vol. 54, pp. 934–942, 1935.

[9] Wilson, C. T. R., Investigations on lightning discharges and on the electrical field of thunderstorms, Phil. Trans. Roy. Soc., ser. A, vol. 221, pp. 73–115, 1920.

[10] Wilson, C. T. R., Some thundercloud problems, Journ. Franklin Inst., vol. 208, pp. 1–12, July 1929.

There are normally present in each cubic centimeter of the atmosphere about 1,000 positive and 800 negative "small" ions [11] having mobilities of about a centimeter per second under the action of a field of a volt per centimeter, as well as 1,000 to 60,000 "large" ions of much smaller mobilities. These ions are, according to Wilson, greatly increased in number in thunderclouds by ionization attending the strong electrical fields in such clouds. The positive ions travel toward the negatively charged earth with a velocity dependent upon the field strength in the region through which they are passing. Similarly, the negatively charged ions travel away from the earth.

Wilson points out that the rain drops falling or rising in the air currents of the thunderstorm must meet many such ions. However, for the electrification to start it is necessary to consider, as in the Elster and Geitel theory, the separation of charge in drops due to the effect of the field of the earth. Since the earth is negatively charged these drops must be polarized with their lower surface positively charged and their upper surface negatively charged. Drops falling toward the earth faster than the velocity of positive ions in that direction will not be overtaken by them. They therefore cannot acquire a positive charge through attraction of such positive ions to the upper negatively charged surface of the drops. On the other hand, the positive ions which the drop catches up with in its fall will be repelled by the positive charge on the lower surface of the drop and so cannot contact it. Negative ions, however, which the drop meets will be attracted to the lower surface of the drop. The larger faster-falling drops by repeated contacts with negative ions thus become negatively charged. As they accumulate in the lower part of the cloud, their field adds greatly to that of the earth in polarizing the drops above them and thus aids in the electrification process. Drops falling more slowly than the positive ions will be overtaken by them. The positive ions will be attracted to the upper negatively charged surface of the drops. By repeated contacts these drops will thus become charged positively. Smaller droplets carried upward by the air currents will likewise become charged positively. Thus Wilson conceives that the upper region of a cloud becomes positively charged and the lower region negatively charged.

Wilson explains the discrepancy between the apparent preponderance of clouds with negatively charged bases and Simpson's measurements which show a preponderance of positively charged rain from thunderclouds by reasoning similar to that just given. He points out that water drops below the negatively charged base of the cloud will be polarized with their tops positive and their bottoms negative. This follows since the negative cloud field will be much stronger than that of the earth. Falling drops will thus attract to their negative undersurfaces the upward moving positive ions. Drops which are negatively charged when they leave the cloud therefore may become positively charged during their passage to earth.

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[11] Hess, V. F., The electrical conductivity of the atmosphere and its causes, D. Van Nostrand Co., New York, 1928.

COMPARISON OF THUNDERSTORM THEORIES

To facilitate comparison of the three theories outlined, they are summarized in table I. Of these theories the breaking-drop theory appears to be the most attractive. Profuse breaking of raindrops must occur in the violent convection systems known to be present in thunderclouds. Laboratory experiments have proved that when drops are broken up in an air stream they become electrified. It is natural to infer that a similar action on a very large scale occurs in thunderclouds. Yet there is one serious discrepancy. This is that laboratory experiments indicate that the water drops become positively charged in breaking, and that therefore the lower most active region of the thundercloud should be a region of positive charge concentration. This is in direct disagreement with measurements of the polarity of lightning-discharge currents through transmission-line towers, which indicate that a very high percentage of strokes striking transmission lines are from negatively charged clouds. While, as Lewis and Foust [12] have suggested, there is a possibility that the transmission towers and lines may exert a directive action on strokes when the clouds are negatively charged and thus cause the high percentage of negative strokes to towers, still the discrepancy is so great that for the present the breaking-drop theory, in spite of its attractiveness, cannot be completely accepted.

TABLE I.—*Comparison of theories of the electrification of thunderstorms*

Author of theory	Electrifying process	Agents	Cloud polarity	
			Upper pole	Lower pole
Simpson	Breaking of raindrops	Wind and gravity	−	+
Elster and Geitel	Contact and separation of polarized raindrops.	Wind, gravity, earth's electric field, electric field due to charged regions in the cloud.	+	−
Wilson	Selective contact of polarized raindrops with air ions.	Wind, gravity, earth's electric field, electric field due to charged region in cloud, attraction and repulsion between air ions and polarized raindrops.	+	−

It is probable that all three of the electrifying processes embodied in the theories described account in part for the electrification of thunderclouds. Which of them is the most important, however, cannot be decided from our present knowledge. As R. A. Watson

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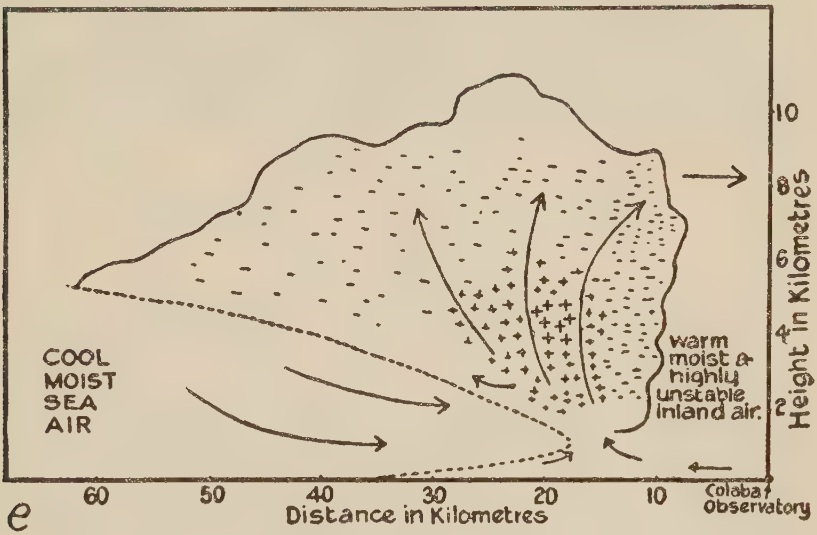
[12] Lewis, W. W., and Foust, C. M., Lightning investigation on transmission lines: III, Amer. Inst. Elec. Eng. Trans., vol. 52, pp. 475–480, 1933.

Watt [13] has pointed out, the difficulties involved in obtaining accurate information on the processes going on in thunderclouds are tremendous, and it is probable that it will be a long time before sufficient knowledge can be obtained to solve the problem.

BANERJI'S THUNDERSTORM MODEL

Banerji [14] [15] has proposed a thunderstorm model, shown in figure 2, in which a region of high negative charge concentration precedes a region of high positive charge concentration, at the front of the cloud. Jensen has photographed lightning discharges while recording the instantaneous field changes caused by them. His results appear to favor Banerji's storm model. Plate 1, figure 2, is a composite picture, taken by Jensen,[16] showing two discharges half a minute apart at the front of a storm. The cloud is moving from left to right. The discharge to the right was from a negatively charged region in the cloud, while the one to the left was from a positively charged region. This is in agreement with Banerji's prediction.



Royal Meteorological Society

FIGURE 2.—Distribution of electrical charge in a thunderstorm. (After Banerji.)

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[13] Watt, R. A. Watson, The present position of theories of the electricity of thunderstorms, Quart. Journ. Roy. Meteorol. Soc., vol. 57, pp. 133–142, 1931.

[14] Banerji, S. K., The electrical field of overhead thunderclouds, Quart. Journ. Roy. Meteorol. Soc., vol. 56, pp. 305–331, 1930.

[15] Banerji, S. K., The electrical field of overhead thunderclouds, Phil. Trans. Roy. Soc., ser. A, vol. 231, pp. 1–27, 1932.

[16] Jensen, J. C., The branching of lightning and the polarity of thunderclouds, Journ. Franklin Inst., vol. 216, pp. 707–748, Dec. 1933.

ELECTRICAL FIELD RECORDS

Measurements of the electrical fields of thunderstorms have added considerably to our understanding of the operation of the thundercloud as an electrical generator. Several investigators [2] [9] [15] [17–21] have obtained records by different methods in the United States, England, India, South Africa, Japan, and Sweden, all showing the same general type of generation curve. A typical record obtained by Wilson [9] is shown in figure 3. This shows the regeneration of the electrical field between a cloud and the earth after a stroke. The curve reminds one of the charging curve of a condenser. In other words, the regeneration of charge is much more rapid at the beginning and decreases with increase in the amount of electricity accumulated in the charged region. This is contrary to what would be expected if the separation of electricity by the air currents continued unhindered. In such a case a straightline increase of charge, and therefore of electric field, would be expected.

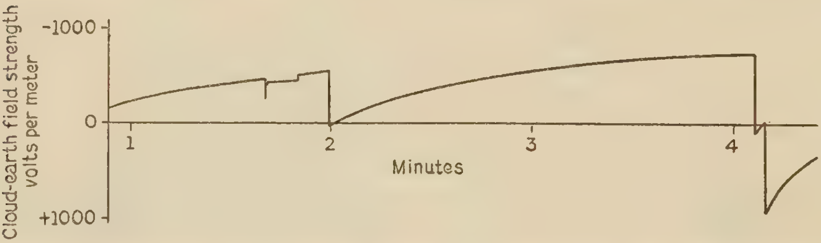

FIGURE 3.—Regeneration of the electrical field between a cloud and the earth after a lightning discharge. (After Wilson.)

Wilson has advanced two reasons for the shape of the charging curve. The first corresponds to the counter-electromotive force principle which determines the shape of the charging curves of condensers. As the electrical field between the two charged regions of the cloud increases, greater and greater opposition is offered to the movement of the larger drops toward lower levels of the cloud and of the smaller drops toward upper regions. This is obvious because the negative charge in the lower regions of the cloud repels the large negatively charged drops while the positive charge of the upper

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[17] Schonland and Craib, The electric fields of South African thunderstorms, Proc. Roy. Soc., ser. A, vol. 114, pp. 229–243, 1927.

[18] Halliday, E. C., Polarity of thunderclouds, Proc. Roy. Soc., ser. A, vol. 138, pp. 205–229, 1932.

[19] Wormell, T. W., Currents carried by point discharges beneath thunderclouds, Proc. Roy. Soc., ser. A, vol. 115, p. 443, 1927; also Vertical electrical currents below thunderstorms and showers, Proc. Roy. Soc., ser. A, vol. 127, pp. 567–590, 1930.

[20] Norinder, H., Electric thunderstorm field researches, Electrical World, vol. 83, pp. 223–226, Feb. 2, 1924.

[21] Nukiyama and Noto, Charges of thunderclouds, Japanese Journ. Astron. and Geophys., vol. 6, pp. 71–81, 1928.

regions attracts them. Similarly, the small positively charged drops being carried up by the air currents are repelled by the charge at the top of the cloud and attracted by that in the lower part of the cloud. This opposition, of course, increases in proportion to the increase in field as the centers of charge are replenished. The second reason advanced by Wilson for the lower rate of field increase as the charge builds up is the greater dissipation of energy due to local ionizations in the intense fields about charged regions as their voltages are increased.

Summarizing, electrical field measurements graphically show the separation of charge and its accumulation in limited regions in the cloud; show how this charge is removed or neutralized by a lightning stroke; and show how after a stroke the electrification process builds up the charge again to the value necessary to cause another discharge.

CHARACTERISTICS OF THUNDERSTORMS

SINGLE THUNDERSTORMS

Upon the approach of a thunderstorm, strong gusts of wind are frequently experienced blowing from the storm toward the point of observation. In the distance, heavy rain can be seen falling with frequent lightning discharges occurring near the front of the rain area, as in plate 2, figure 1. On the nearer approach of the storm, a scattered fall of large rain drops or possibly a light rain occurs. This is soon followed by a heavy downpour usually accompanied or immediately preceded by the heaviest lightning of the storm, as the front of the rain area and the lightning discharge center arrive overhead. As the storm cloud is carried along with the general air movement, lightning soon starts striking beyond the point of observation, rain settles down to a steady downpour, and the observer realizes that the worst of the lightning for that section of the storm is past.

Thunderstorms viewed from a distance frequently show several prominent thunderheads resulting from the formation of several convection systems within them. Each of these systems may produce one or more lightning discharge centers. Therefore a succession of conditions and events as described for a single center is often experienced during the passage of a thunderstorm.

It is apparent that in many storms the discharge centers are of relatively limited dimensions. By knowing the velocity of travel of the cloud, it would be possible to form a fair estimate of the length of a center in the direction of storm movement. As an illustration, assume 20 miles per hour for the velocity of a particular thunderstorm and 1 minute as the time during which discharges were occurring directly overhead. For the assumed conditions, the center would be about 1,800 feet long. Some centers are obviously much greater in extent.

Our present knowledge of the shape and extent of lightning discharge centers is too meager to establish a "usual" size for centers, if such a size actually occurs. They must vary considerably from storm to storm. It is important that their range be determined, for upon their shape and size depends the nature of the electrical field near the cloud. This electrical field in turn probably initiates the lightning stroke.

When the discharge center is of limited dimensions compared with its height above ground, the electrical field will be much more intense near the cloud than near the ground. In such a case, it would not be expected that earthed objects would have much effect in initiating a lightning stroke. If, on the other hand, the dimensions of the center should be large compared with the height of the center above ground, much more importance would have to be attached to the effect of grounded objects in causing strokes. This information is obviously of considerable importance in lightning protection problems.

The polarity of the discharge center near the front of a storm according to Simpson's theory should be positive, while according to Elster and Geitel's and Wilson's theories it should usually be negative. According to Banerji it should consist of a negative front center followed by a positive center. Although it has been shown that 95 percent of the strokes to transmission lines are negative, yet measurements of electrical field changes resulting from lightning strokes indicate a more nearly equal distribution of positive and negative strokes. Indirect measurements by Norinder [22] of the polarity and magnitude of lightning currents, made by measuring the electromagnetic fields caused by strokes, likewise show a considerably higher percentage of positive strokes than is indicated by measurements of currents in transmission towers. Further work seems necessary to determine the relative frequency of occurrence and activity of positive and negative discharge centers.

The measurements made of lightning strokes to transmission lines, using magnetic links as a means of measurement, have indicated in many cases reversal of current. These results, together with those of Norinder, coupled with a consideration of the probable location of cloud charges, strongly suggest the possibility of reversal of polarity between successive discharges constituting a multiple stroke. This reversal of polarity may well result from various tappings of positive and negative accumulations of charges within the cloud.

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[22] Norinder, H., Lightning currents and their variations, Journ. Franklin Inst., vol. 220, pp. 69-92, July 1935.

SHIFTING OF DISCHARGE CENTERS

From the foregoing one might be left with the conception of a thunderstorm proceeding over the country with one or more discharge centers always maintained at the same locations in the cloud. This conception must be modified because, as the storm travels, moisture-laden air is not constantly supplied to the same part of the cloud. Air is naturally stratified, and nonhomogeneous, so that conditions are not constantly favorable in front of the centers for a supply of moist air. Topographical conditions, the presence of rivers, etc., also affect the position and amount of moisture-laden air supplied to a given part of the cloud. As a consequence, the regions of greatest convection shift about in the cloud as it travels. Old centers discharge their electrical energy and, since the convection currents have decreased greatly, fresh accumulations of charge occur more slowly. Discharges therefore occur less often or cease. Meanwhile, a nearby region in the cloud may be more favorably supplied with moisture. A convection system of sufficient intensity to electrify the rain drops and separate the oppositely charged particles then develops in that region. Thus a new center is born, and lightning discharges occur from it.

FAMILIES OF THUNDERSTORMS

When conditions over a wide area are favorable for the formation of thunderstorms, a number of such storms may be formed and several may pass over the same region within an hour or so of each other. If these occur at night and people are not in a position to watch the storm movement accurately, they frequently get the impression that the same storm "hangs around all night", paying them repeated visits. Actually, the general air movement at the cloud level has carried them a succession of storms. In the daytime several members of a family of such thunderstorms can frequently be seen at one time from good observation points.

CAUSES OF THUNDERSTORM FORMATION

The necessary conditions for the formation of a thundercloud are: (1) the presence of sufficient moisture in the atmosphere; (2) the presence of meteorological and (or) topographical conditions favorable to the movement of moisture-laden air up to the condensation level; and (3) conditions favorable to the formation of sustained strong upward convection systems.

There are five general types of thunderstorms, the type depending on the nature of the meteorological and topographical conditions. These are the heat, the mountain, the cold-front, the overrunning-cold-front, and the warm-front thunderstorms.

THE HEAT THUNDERSTORM

Hot humid days with little or no general horizontal movement of air near the earth's surface are favorable to the formation of heat thunderstorms. Such days are likely to occur when horizontal pressure gradients are weak and temperature is high over extended regions. Typical meteorological conditions of this character are illustrated by the weather map reproduced in figure 4 and described by Humphreys [23] in Physics of the Air.

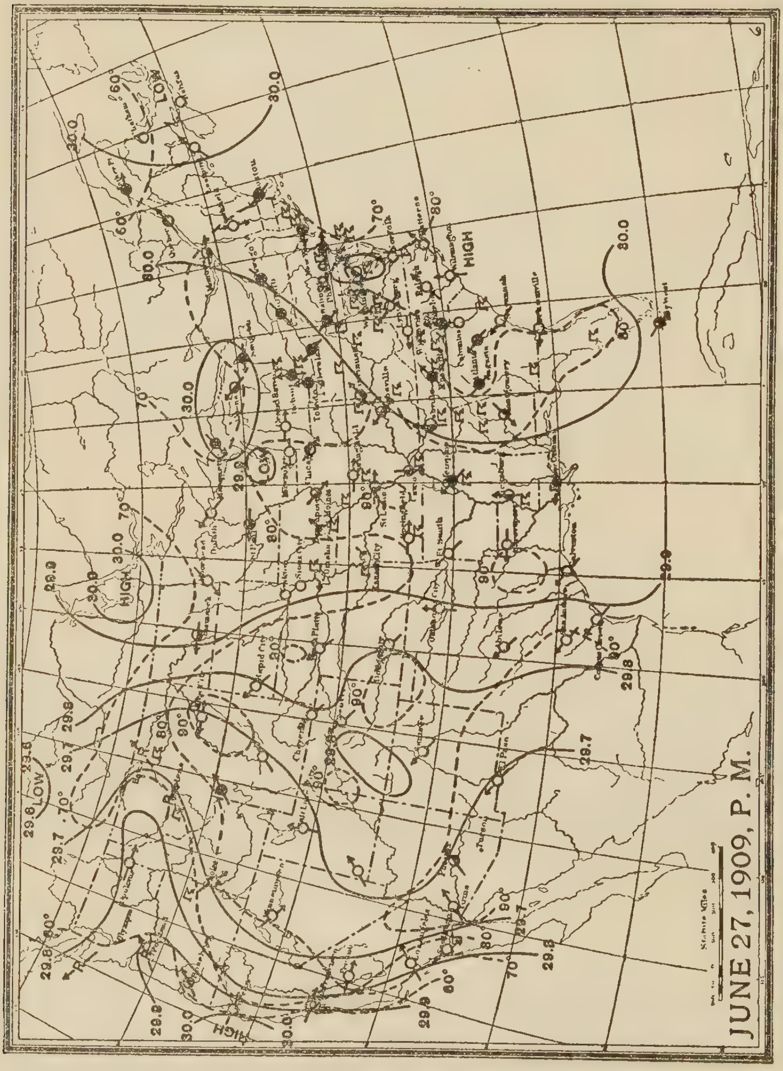

FIGURE 4.—United States weather map, 8 p. m., June 27, 1909, typical of heat thunderstorms: ○, clear; ◐, partly cloudy; ●, cloudy; *R*, rain; ⋉, thunderstorm. (After Humphreys.)

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[23] Humphreys, W. J., Physics of the Air, McGraw-Hill Book Co., Inc., New York, 1929.

Another important condition must be satisfied before a heat thunderstorm can occur. This is the establishment, in the region where the storm originates, of a dry adiabatic or superadiabatic temperature gradient from the earth up to the cloud level. That is, a condition must be established in which the temperature of the air decreases with increase in height above the earth at the same or a greater rate than unsaturated air, warmed at the surface, cools as it rises and expands adiabatically.[24] This requires time, for normally the rate of decrease of air temperature with height is only about half the required dry adiabatic temperature gradient. Frequently a day or two of hot weather seems to be necessary before such a gradient can be established by progressive convection and mixing of the air.

When an adiabatic gradient is established, air heated at the surface can rise to the condensation level. There its moisture will begin to condense and in doing so will give off its latent heat of condensation. This heat warms the rising column of air. The resulting temperature difference between the rising column of air and the surrounding air increases the upward air movement and helps to produce the violent convection necessary to electrify clouds.

A heat thunderstorm will thus form if (1) a temperature gradient equal to or greater than the dry adiabatic has been established between the ground and the condensation level, (2) the general horizontal air movements are mild enough and other conditions are favorable to the strong local heating of the surface air, and (3) if this air contains sufficient moisture.

MOUNTAIN THUNDERSTORMS

Mountain thunderstorms are closely related to heat thunderstorms. The slopes of the mountain are heated by the sun's rays. They reradiate this heat energy at a longer wave length which can more readily be absorbed by the atmosphere than the sun's direct shorter-wave-length radiation. The air near the mountain slopes is thus heated to a temperature above that of the surrounding air. This relatively warm column of air can be compared to the warm air in a huge chimney tipped at a considerable angle from the perpendicular. In a chimney the difference in weight of the column of warm air within the chimney compared with a column of equal area and height outside of the chimney supplies the necessary pressure to force air up the chimney. Similarly, the greater weight of a column of relatively cool air in the free atmosphere at a moderate distance from a mountain, compared with the weight of a column of the warm air near the surface of the mountain, results in a pressure difference forcing the warm moisture-laden air up the mountain side and toward the condensation level. This chimney action of a mountain thus aids greatly in thunderstorm formation by making it unnecessary to establish an adiabatic temperature gradient through the free atmosphere up to the cloud level. An example of a thunderstorm forming over a mountain is shown in plate 2, figure 2.

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[24] By adiabatic expansion is meant expansion during which no heat is added to or subtracted from the expanding system. This condition is nearly realized when air expands while rising rapidly.

Mountains also aid in the formation of thunderstorms by deflecting upward the air masses which are blown against them. The kinetic energy of the moving air carries it up the slopes toward the condensation level.

COLD-FRONT THUNDERSTORMS

In many sections of the United States after a period of warm, humid weather, thunderstorms frequently occur followed by clear, cool, dry weather. These may easily be confused with heat thunderstorms. Since before these storms the air is warm and moist while after the storms it is cool, dry, and clear, it is perhaps natural to ascribe the clearing of the atmosphere to the thunderstorm. Actually a large mass of cool dry air has moved into the region and replaced the warm humid air which was there previous to the storm, and in doing so has caused the thunderstorm. The cool air is usually of polar or near-polar origin and is responsible for the bright clear days following the storm. The warm humid air which it replaces is frequently of tropical or near-tropical origin.

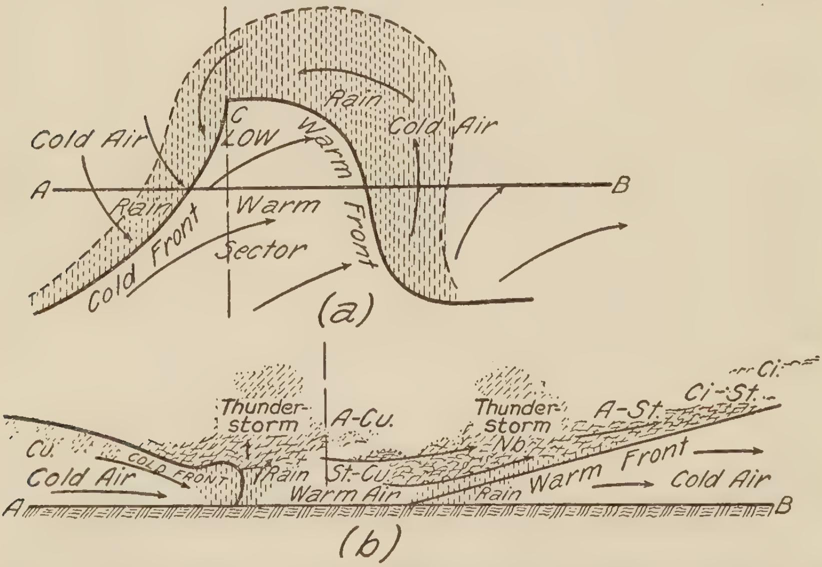

FIGURE 5.—Horizontal (*a*) and vertical (*b*) cross-sections through a low-pressure system, showing the cold-front and the warm-front. Ci., Ci-St., etc., refer to types of cloud. (After Bjerknes and Solberg.)

As stated, these thunderstorms are caused by the action of the cool dry air mass on the warm humid air mass. Cool air traveling from the northwest along the rear of a LOW (low-pressure area) overtakes warm air moving from the south and southwest into the southern sector of the LOW. The surface along which the front of the cool air mass makes contact with the warm air is called the cold-front. It is along this "squall line" or storm line that the thunderstorms are formed. Figure 5,[25] [26] reproduced from National Research Council Bulletin, no. 79, shows horizontal and vertical sections through the cold- and warm-fronts attending a LOW. In section (*a*) a view is shown looking down from above the earth upon a LOW. Referring to that part of the diagram which lies to the left of the dashed vertical line, and disregarding the part to the right of this line which will be described under "Warm-front Thunderstorms", the cold front is indicated by the line extending downward and to the left. A vertical section through this cold front is shown in the lower left-hand side of figure 5. It will be noted that the cold air mass has an overhanging front. The overhang frequently may be 4 miles long.[25] It results from retardation of the surface air layers by friction with the ground and consequent overrunning of these layers by the faster-moving higher air. Warm air is trapped beneath this overhanging front. In the resulting instability due to cold air above warm, the warm air rises rapidly and forms strong convection systems which often are of sufficient magnitude to produce thunderstorms. As the wedge of cold air advances, it also underruns the warm air and forces it upward, contributing in this way to thunderstorm formation. Thunderstorms formed by these causes are called cold-front thunderstorms.

OVERRUNNING-COLD-FRONT THUNDERSTORMS

When, instead of the front of a cool air mass overrunning a warm mass of air near the surface of the ground, it does so at a higher level for a number of miles in front of the surface cold-front, the unstable conditions of cool air above warm air may occur over a much larger area. Thunderstorms which occur because of this condition are called overrunning-cold-front thunderstorms.

WARM-FRONT THUNDERSTORMS

It frequently happens that ahead of the warm sector of a LOW there exists a region of relatively cool air. The front of the advancing warm mass of air is called a warm-front. Its location is shown in figure 5, *a*, by the line extending downward and to the right. The scale of the diagram causes the warm-front and the cold-front to appear close together. Actually, the warm sector is frequently several hundred miles across so that a day or more may go by after the passage of a warm-front before the cold-front arrives.

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[25] Bjerknes, J., and Solberg, H., Life cycle of cyclones and the polar front theory of atmospheric circulation, Geofysiske Publikationer, vol. 3, no. 1, 1922.

[26] Physics of the earth—III. Meteorology. Nat. Res. Counc. Bull., no. 79, published by Nat. Acad. Sci., Washington, D. C., 1931.

Referring to figure 5, *b*, the warm air at the front of the warm sector is forced upward over the cold wedge of air ahead of it. The phenomenon is much more gradual than in the case of the cold-front, and frequently several hours' warning of its approach is given by the changes in the nature of clouds as indicated in the diagram. An observer at *B* would first see a few wisplike cirrus clouds high above him. These would increase in number until they formed a high unbroken layer of clouds. As the warm-front approached nearer and nearer, more and more moisture would be available for cloud formation, and the clouds would gradually form at lower and lower levels. The gradual change from scattered cirrus through cirrostratus, alto stratus, and stratus to nimbus or cumulo nimbus therefore gives ample warning of a coming disturbance and evidence of the nature of the disturbance. Thus, an observer familiar with cloud types can frequently predict the coming of rain with possible thundershowers after observing the first two or three transitions of the cloud types mentioned.

Application of knowledge of warm- and cold-fronts should be of value to those interested in predicting the weather from United States Weather Bureau maps. By remembering that the warm-front line and the cold-front line meet at the center of a LOW, and that the warm sector lies to the south of the LOW, the position of the fronts can be approximated on the weather map. Knowledge of their locations and indicated strength will aid considerably in making predictions from the maps.

MAINTENANCE OF THUNDERSTORMS

Humphreys has suggested a plausible explanation for the manner in which the electrical activity of a thunderstorm is maintained as it travels over the country. Referring to figure 6, from Humphreys'[23] Physics of the Air, two main air currents are indicated. A strong relatively cold column of air, formed as the result of cooling by contact with cold rain from high within the cloud and evaporation of this rain, descends from a region near the front of the rain area and presses forward near the ground in front of the advancing storm as shown by the downward arrows. It acts as a huge moving wedge forcing warmer moisture-laden air up toward the cloud as shown by the upward arrows, and thus maintaining its supply of moisture. Without this the storm would not be maintained after the original supply of moisture had fallen in the form of rain.

The movement of cool air downward and outward from the rain area of a thunderstorm, as described by Humphreys, is frequently indicated by the shape of the rain line when a storm is viewed from the side. Thus, in the thunderstorm shown in plate 1, figure 1, the downward and outward sweep of the rain line is undoubtedly due to such air currents. In this particular photograph, which was taken by one of the authors from a mountain top in northern Idaho, the rear of the rain area is shown. Similar air currents blow from the fronts of thunderstorms. By assuming that this photograph shows the front of a storm moving toward the right, the shovellike action of the air currents can be readily visualized.

The upward movement of warmer air, which is caused by the shovel action of the cold air currents, is made evident by the upward movement of small cloud fragments called scud cloud which frequently are present below the main cloud base. At times these can be seen moving up toward the cloud base at very high velocities. The presence of the adjacent upward and downward moving air columns is also shown by the rotation of a mass of condensed vapor (called the roll scud) which is sometimes plainly visible just below the cloud base at the front of the rain area. Its direction of rotation and location are shown at *S* in figure 6. A roll scud rotating as shown in the diagram has been seen at the front of a storm by one of the authors during thunderstorm studies [2] in Colorado.

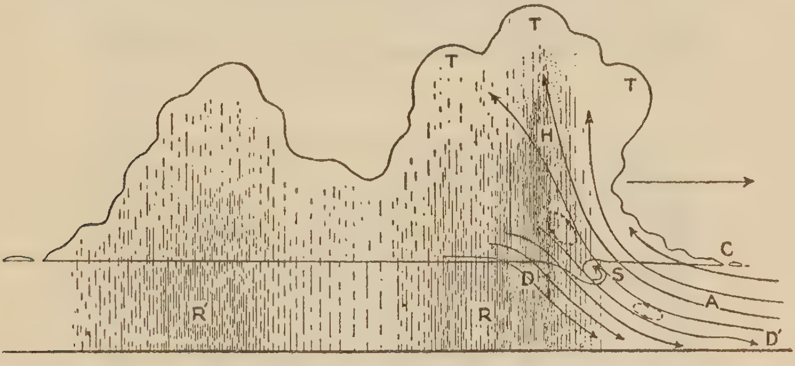

FIGURE 6.—Schematic cross-section of a thunderstorm showing adjacent downward and upward air currents which help maintain the storm. *A*, ascending air; *D*, descending air; *C*, storm collar; *S*, roll scud; *D′*, wind gust; *H*, hail; *T*, thunderheads; *R*, primary rain; *R′*, secondary rain. (After Humphreys.)

THUNDERSTORM PREDICTIONS

FREQUENCY

An estimate of the number of thunderstorm days to be expected in any part of the United States per month and per year can be made from Alexander's [27] isokeraunic [28] maps, shown in figures 7–11. These

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[27] Alexander, W. H., Distribution of thunderstorms in the United States, Mon. Weather Rev., vol. 52, p. 337, 1924.

[28] Equal frequency of thunderstorm days.

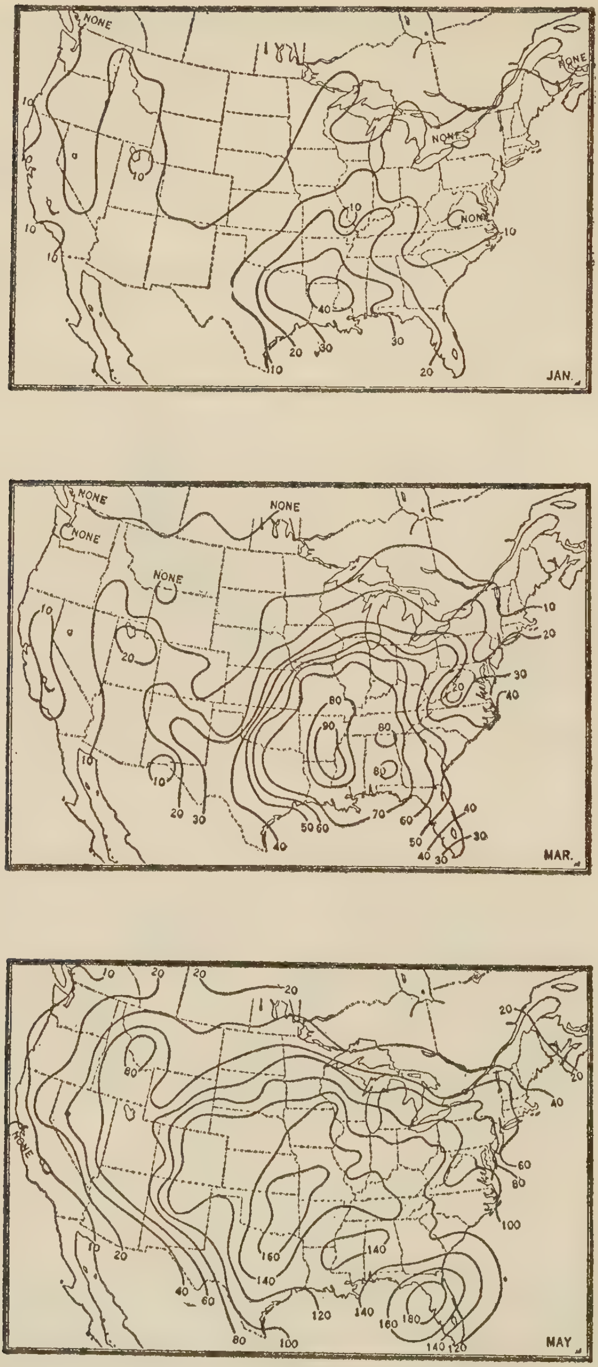
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FIGURE 7.—Monthly isokeraunic maps based upon the total number of thunderstorm days occurring each month over the 20-year period 1904–23. Divide the numbers on the maps by 20 to obtain the average number of thunderstorm days to be expected per month. (After Alexander.)

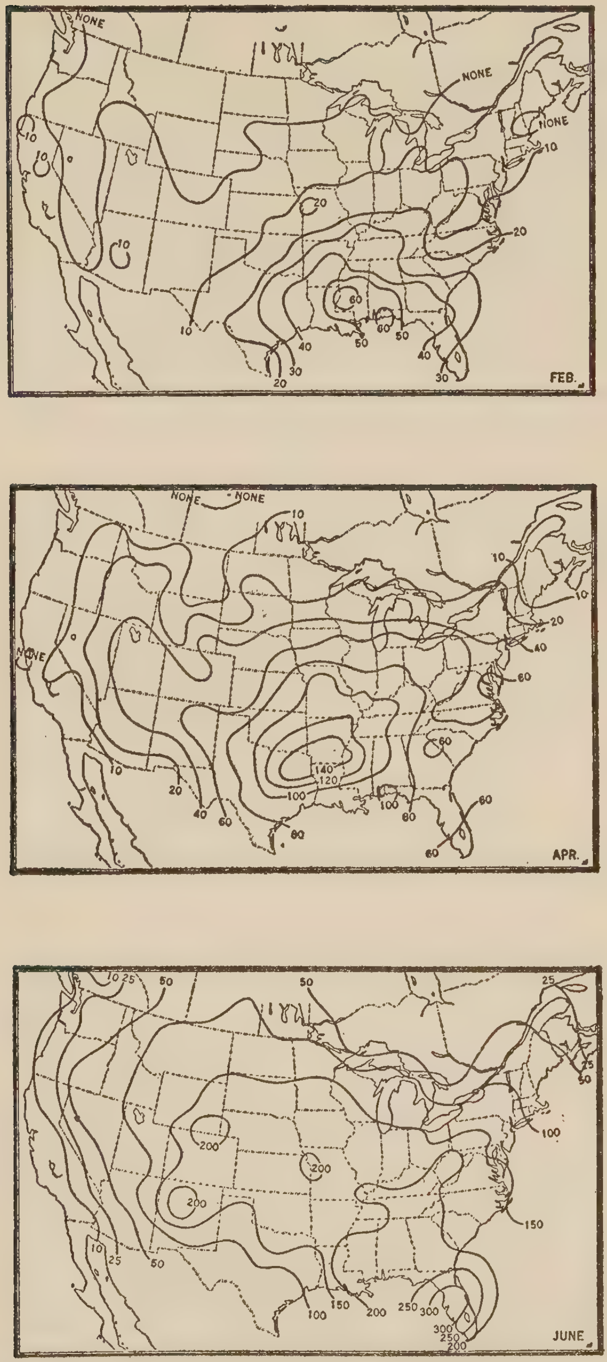
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FIGURE 8.—Monthly isokeraunic maps based upon the total number of thunderstorm days occurring each month over the 20-year period 1904–23. Divide the numbers on the maps by 20 to obtain the average number of thunderstorm days to be expected per month. (After Alexander.)

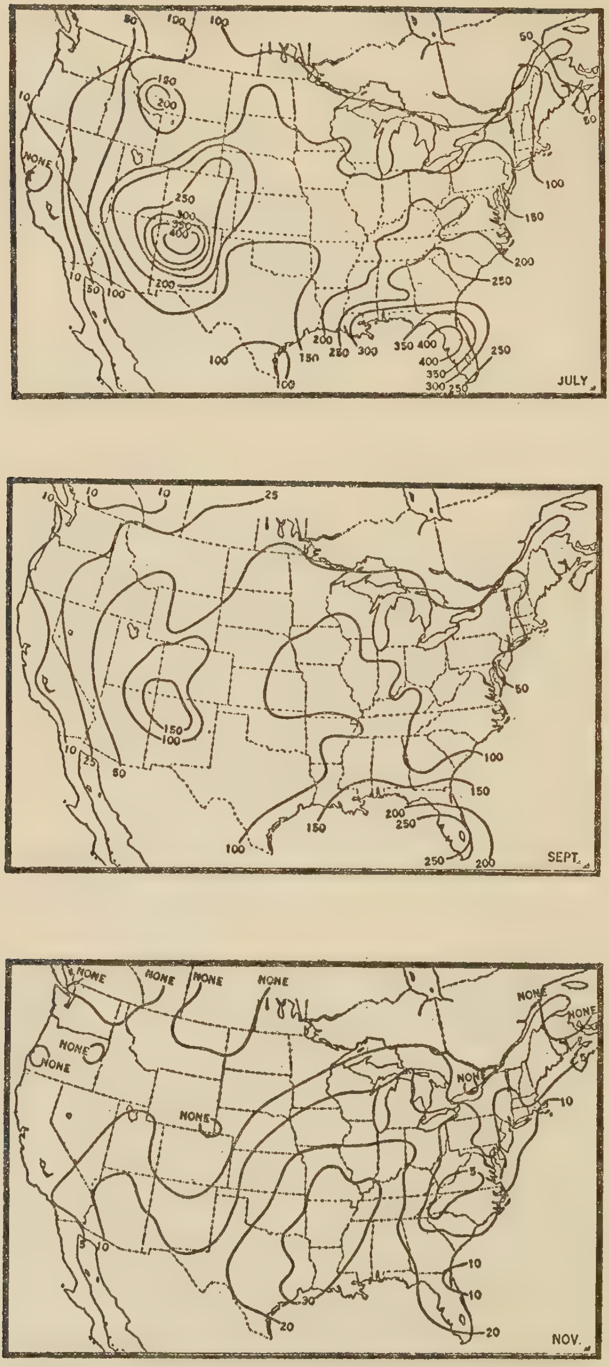
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Figure 9.—Monthly isokeraunic maps based upon the total number of thunderstorm days occurring each month over the 20-year period 1904–23. Divide the numbers on the maps by 20 to obtain the average number of thunderstorm days to be expected per month. (After Alexander.)

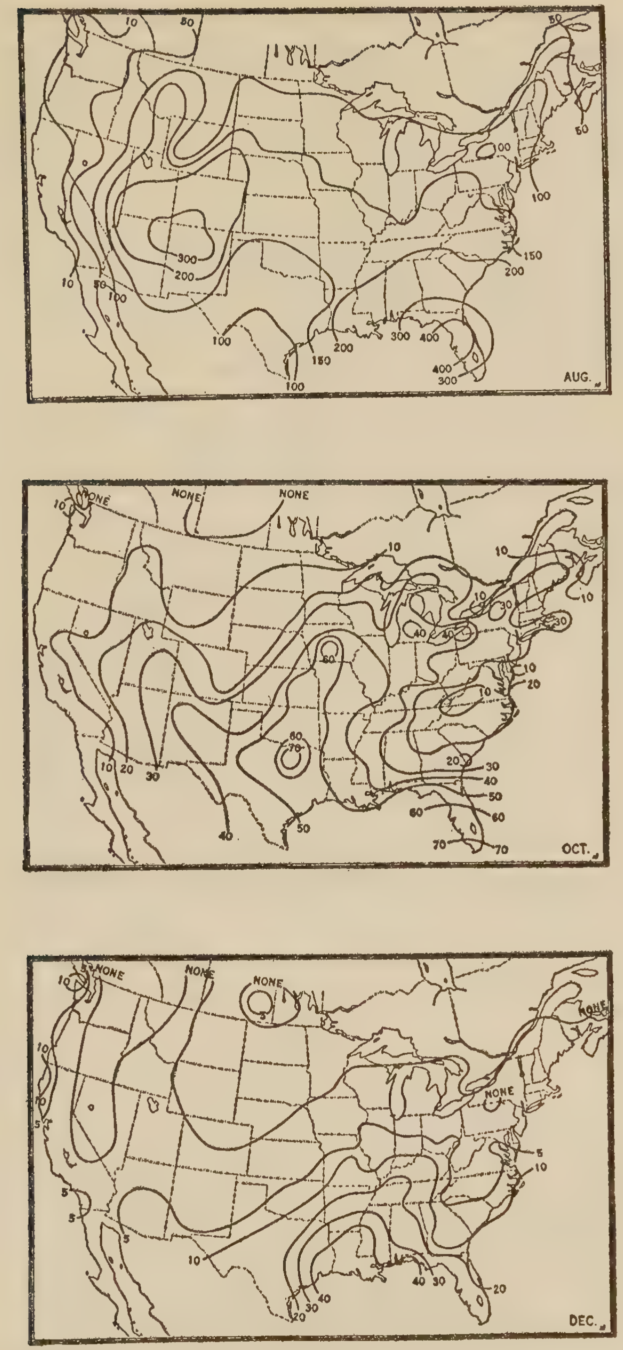
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Figure 10.—Monthly isokeraunic maps based upon the total number of thunderstorm days occurring each month over the 20-year period 1904–23. Divide the numbers on the maps by 20 to obtain the average number of thunderstorm days to be expected per month. (After Alexander.)

maps were prepared from United States Weather Bureau records of thunderstorm occurrence at stations scattered over the United States. The records covered a 20-year period. One must, of course, know the United States Weather Bureau's definition of a thunderstorm in order to interpret the charts. Their observers were instructed to report a thunderstorm if they could hear thunder. This probably limits the range of each station to a roughly circular area frequently not over 10 miles and probably never over 20 miles in radius, since it is doubtful whether thunder can be heard farther than that. This range would vary greatly from station to station. Stations in noisy locations in large cities would probably report fewer than the actual number of storms on account of the masking of the thunder by other noises. While the data are subject to these limitations, still they are the best available on thunderstorm occurrence in the United States.

Alexander has reviewed his monthly thunderstorm maps as follows:

> During the winter months—December, January, and February—the center of thunderstorm activity for the United States is in the vicinity of Vicksburg (Miss.). In February, however, the general thunderstorm area tends to drift southeastward, with a marked secondary over Pensacola (Fla.). In March the center of activity is still over the lower Mississippi Valley, with the general storm area spreading rapidly northeast over the Tennessee and Ohio Valleys. In April the center appears to be in the vicinity of Shreveport (La.), with the general area spreading northeast over a large part of the Eastern States, but also north and west.
>
> The interesting thing about the May chart is the definite appearance of the primary center over Tampa (Fla.), and a strong secondary over the lower plains States. Great thunderstorm activity now prevails over the entire eastern half of the country, except in the Canadian border States, including the whole of New England. There is also an increased activity in western Montana.
>
> During June the thunderstorm area continues to spread northward and covers the entire country east of the Rocky Mountains except possibly the extreme northeast. The center of greatest activity is in the vicinity of Tampa. One of the most surprising things revealed by the July chart is the increased activity over the Rocky Mountain States, with a secondary over Santa Fe (N. Mex.), almost as strong as the primary over Tampa. Marked activity also continues in southwestern Montana and in the vicinity of Yellowstone Park. The distribution in August is very much the same as in July, but with a notable decrease in intensity along the Canadian border and a marked weakening of the center over Santa Fe. The two centers, at Tampa and Santa Fe, persist, though weakening through September. In October the southeastern (Tampa) center seems to have dropped a little south and is now over Key West, while the Santa Fe center has disappeared or shifted to eastern Texas and the southern plains States, and the general storm area is rapidly diminishing. In November, as during the winter months, the active area is over the lower Mississippi and Ohio Valleys.
>
> Chart 13 (reproduced as figure 11 in this article), which shows the average annual number of days with thunderstorms during the 20-year period at a large number of stations in the United States and Canada, has a number of interesting features and is worthy of considerable study. Note that no part of the country is entirely free from thunderstorms, although they are comparatively rare along the Pacific coast; and that there are two centers of maximum activity, one over Tampa, with an annual average of 94 days with thunderstorms in the 20-year period, and the other over Santa Fe, with an average of 73 during the same period.

UNITED STATES WEATHER BUREAU PREDICTIONS

United States Weather Bureau stations scattered over the United States make daily telegraphic exchanges of information on temperature, pressure, wind, rain, thunderstorms, etc. From these data, weather charts are made up from which weather predictions for each section of the country are made. These include the prediction of thunderstorms and are the best available. It must of course be realized that these stations predict for areas covering many square miles. While each region is subdivided into sections for purposes of prediction, it cannot be expected that all parts of each section will be subjected to the same weather conditions. Those interested in predictions covering a very localized territory must then supplement the Weather Bureau predictions by local observations. With the Weather Bureau's information on regional atmospheric conditions as a base, and with an acquired knowledge of the significance of pressure, temperature, humidity, wind direction, type of cloud, and degree of atmospheric haze, it is frequently possible to predict the occurrence of thunderstorms several hours in advance.

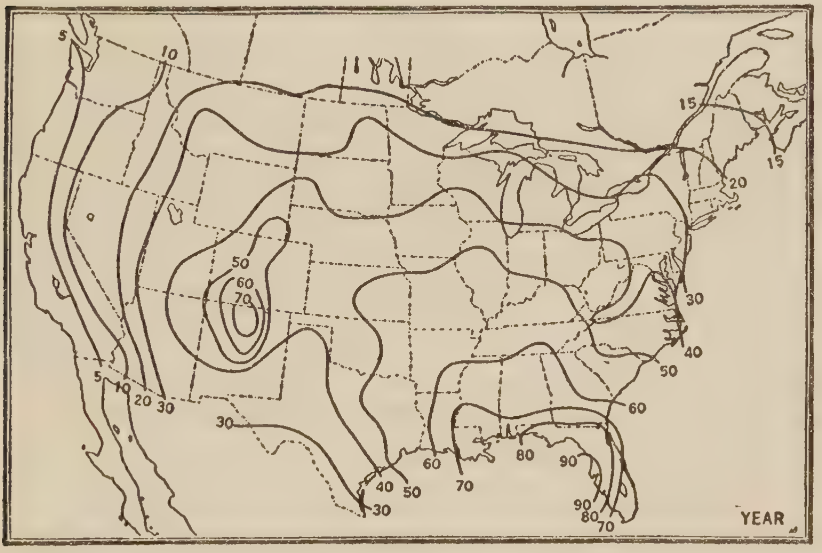


FIGURE 11.—Isokeraunic map indicating the average number of thunderstorm days to be expected per year throughout the United States; based on 20-year records covering the period from 1904 through 1923. (After Alexander.)

DIRECTION OF TRAVEL

Prediction of the direction in which thunderstorms will travel is frequently very desirable. If general air movements at the cloud level are extensive, as is usually the case for cold-front, and warm-front thunderstorms, the direction of thunderstorm travel is easily predictable. The thunderstorms will be carried along with the general air movement. Their movement will then be the same as the direction of cloud travel directly overhead (observations of cloud movements at a considerable angle from the vertical may result in large errors due to perspective).

In the case of heat thunderstorms, which occur most frequently at times when the general air movements are minor, it is more difficult to predict their direction of travel. Direction of cloud travel overhead is helpful but not certain for local topographical conditions and air systems generated by the storm itself may easily cause the storm to take an erratic course.

SEVERITY

The severity of thunderstorms depends upon the extent and violence of their convection systems. This in turn depends upon the magnitude of the temperature differences between the warm moisture-laden air and the air through which it is carried by convection, upon the moisture content of the warm air, and upon the velocity of the general air movement. The intensity of cold-front, overrunning-cold-front, and warm-front storms can thus be predicted qualitatively from the magnitude of the atmospheric instability indicated by Weather Bureau measurements. The intensity of heat thunderstorms can be qualitatively predicted from the humidity, the temperature, and the mildness of the general air movement. The occurrence of high humidity, high temperature, and very little air movement is favorable to a severe storm.

APPLICATIONS OF THUNDERSTORM KNOWLEDGE

TRANSMISSION-LINE LOCATION

While the number of routes by which a transmission line can be run between two locations is limited, it is possible that under certain conditions substantial decreases in exposure to lightning might result from changes of a few miles in line location. This is particularly true in regions where thunderstorms follow preferred paths. Whether they do so in a given locality depends to a large extent on the chief cause of storms there. If thunderstorms are usually of the heat type, or the mountain type, they may well follow such paths, for their formation depends on local favorable meteorological and topographical conditions which tend to remain more or less the same. In the light air movements prevailing when storms of this type are formed, local land and air conditions have a much greater influence on their direction of travel. If, on the other hand, thunderstorms that visit an area are usually of the cold-front or warm-front type, preferred paths will be much less evident. Their formation depends on the interaction of adjacent cold- and warm-air masses often covering hundreds of square miles. They may thus form in widely scattered locations with comparatively little reference to local topographical conditions. Their direction of travel will nearly always be determined by the general air movement at cloud levels.

In regions where thunderstorms are of the heat or mountain type, it may be desirable to consider ridge-top versus valley-side or valley-bottom locations for transmission lines. These storms apparently often tend to follow certain valleys and rivers. In traveling along such valleys, many more strokes may strike into the valleys than to the sides and top of adjacent mountains because lightning discharge centers are often of limited dimensions. This condition has frequently been seen by one of the writers in thunderstorm studies [2] in Colorado. Location of lines along ridge tops may then result in less exposure to lightning.

In regions where thunderstorms are of the cold-front or warm-front types, the haphazard formation of such storms over wide areas and the fact that their direction of travel is usually controlled by the general air movement at cloud levels greatly decreases the likelihood of preferred paths being followed. Storms carried from west to east by the general air circulation will travel over mountain ridges oriented in northerly and southerly directions. The lightning exposure of lines located on the top of such ridges would be greater than for lines located on the valley sides in the lee of the ridge or on valley bottoms.

POWER-SYSTEM PROTECTION

The degree of protection economically justifiable for a given power system depends to a considerable degree on the frequency of occurrence and severity of thunderstorms in the region in which it is located. Alexander's charts should be of value in determining the probable thunderstorm frequency for any section of the United States. This information should be supplemented by knowledge of local storm severity in the region served by the system in order to evaluate the potential hazard due to the storms to be expected there.

POWER-SYSTEM OPERATION

Despite many improvements in operation, lightning still represents a serious source of interruption to many power systems. To insure continuity of service, many systems connect additional generating capacity to their lines when thunderstorms are known to be approaching. Knowledge of the occurrence, direction of travel, and severity of thunderstorms is therefore of importance to them. Weather Bureau reports serve as preliminary warnings of the probable occurrence of thunderstorms. Short-time warnings of the appearance of an actual storm over the system are much more important, however. Some power plants have installed "howlers" which warn the operator that a storm is in the neighborhood. Usually, however, the first warning must come from employees distributed over the system, who, as part of their regular duties, report to the load dispatcher the location, direction of travel, and severity of storms near the system. The dispatcher can determine whether it is liable to affect his system, and can then make the necessary changes in system set-up to minimize the effect of the storm.

AMMUNITION STORAGE

Lightning is a real hazard to ammunition storage depots. Where a choice of locations is possible, a study of thunderstorm conditions should be of value in selecting a location offering minimum exposure. Alexander's charts of thunderstorm frequency should be of value in determining the general region. The most favorable location in this region can then be determined by a localized study of topographical and meteorological factors, advantage being taken of knowledge of the type of storm most prevalent, the location of topographical features such as combinations of mountains and moisture sources which are known to serve as thunderstorm "breeders," prevailing wind directions, preferred storm paths, etc. At times such depots may be located in a position taking advantage of topographical features offering natural shielding against direct strokes.

OIL STORAGE

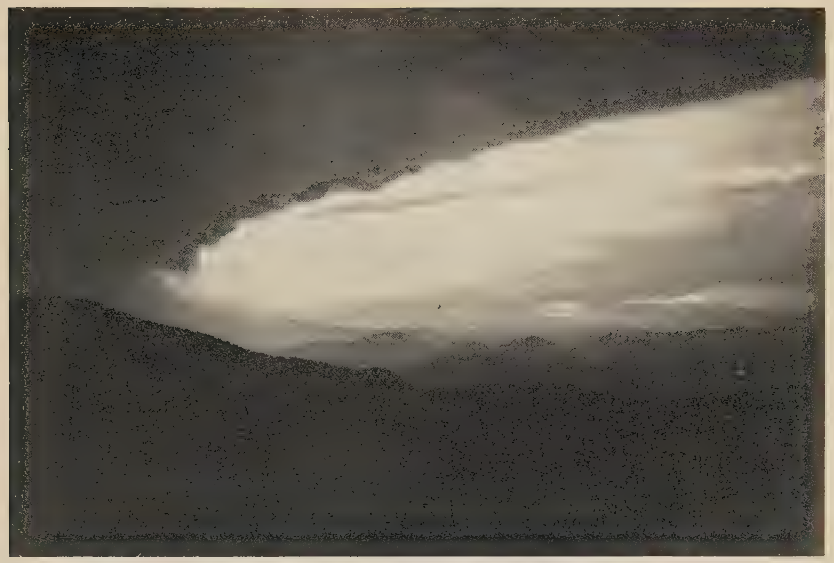
Where a choice of location for the storage of oil is possible, a study of thunderstorm conditions similar to that described for ammunition depots should be worth-while. Here, again, comparatively minor changes in storage location may result in a considerable decrease in lightning exposure.

Although exposure to lightning may be reduced by proper location, this reduction should not be construed to justify a reduction or elimination of lightning protective equipment where lightning is particularly hazardous to the material to be protected. For example, while Alexander's charts show that California enjoys comparative freedom from thunderstorms, still occasional severe storms do occur there and the elimination of protective equipment would be unwise. In 1926, millions of dollars worth of oil and equipment in that State were destroyed by fires set by lightning.

RÉSUMÉ

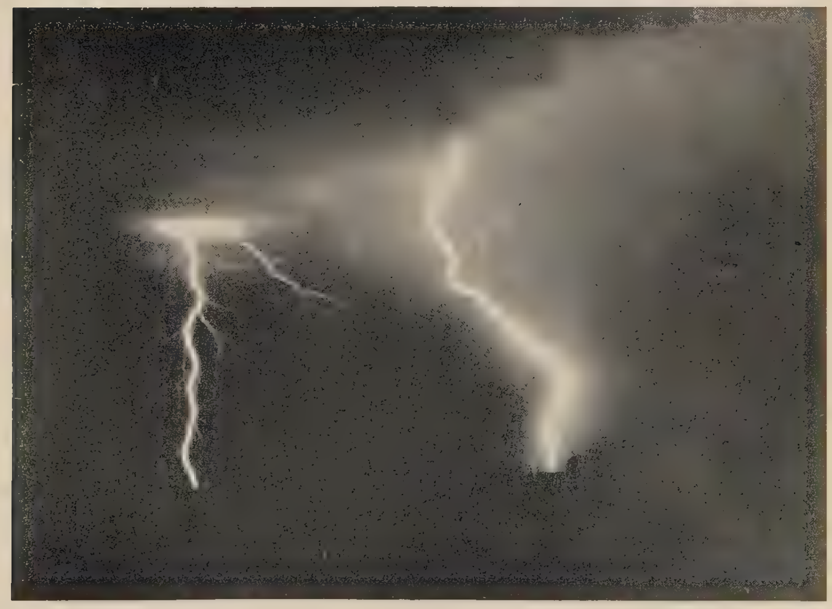
In the foregoing, Simpson's, Elster and Geitel's, and Wilson's theories of the electrification of thunderclouds are reviewed. Experimental evidence and observations bearing upon these theories are given consideration and the characteristics of actual thunderstorms are described. Five types of thunderstorm formation—heat, mountain,

cold-front, over-running-cold-front, and warm-front—are explained. Humphreys' theory explaining how thunderstorms are maintained as they travel over the country is reviewed, and observational evidence is advanced which supports it. Alexander's charts, which indicate the monthly and yearly frequency of occurrence of thunderstorm days over the United States for a 20-year period, are given. Their value in lightning protection planning is pointed out. Conditions under which the occurrence, direction of travel, and probable severity of storms can be predicted are enumerated. The value of application of thunderstorm knowledge to the location of transmission lines, to the determination of economically justifiable power-system protection, to maintenance of continuity of service, and to the location of explosive and oil-storage depots is pointed out.



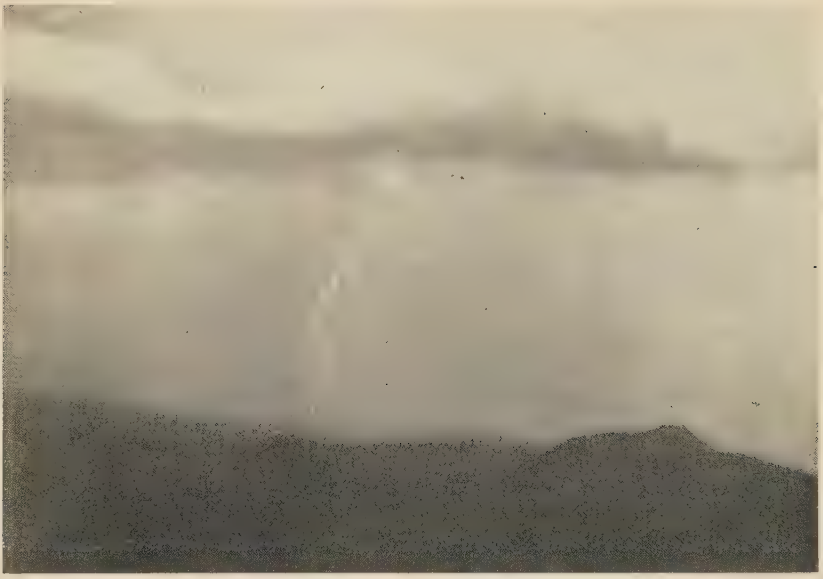
U. S. Forest Service

1. A SEVERE COLD-FRONT THUNDERSTORM PASSING OVER NORTHERN IDAHO.



After Jensen

2. LIGHTNING DISCHARGES FROM ADJACENT POSITIVE AND NEGATIVE CENTERS AT THE FRONT OF A THUNDERSTORM.



1. THE FRONT OF A THUNDERSTORM MOVING TOWARD THE CAMERA; LOCATION OF THE DISCHARGE CENTER NEAR THE FRONT OF THE RAIN AREA IS TYPICAL.

2. A THUNDERSTORM FORMING OVER A MOUNTAIN.

THE ELECTRON:
ITS INTELLECTUAL AND SOCIAL SIGNIFICANCE [1]

By Karl T. Compton
President of the Massachusetts Institute of Technology

Within the past 5 years, centenaries, bicentenaries, and tercentenaries have been much in vogue. Every town or institution or event which has claim to distinction has sought the excuse of the calendar to remind the world of its claims to greatness. Thus we have recently celebrated the centenary of Faraday's discovery of the principles of electromagnetism and the bicentenary of Watt's invention of the steam engine—discoveries which have introduced the eras of electricity and of mechanical power. The city of Chicago has sought to tell us that the progress of mankind really began with the founding of that community, and has led us to spend millions of dollars to gain the impression that there is really some causal relationship between Chicago and world progress. In my part of the country, the city of Boston and its suburbs staged a succession of tercentenary celebrations, as proud of their past as Chicago is of its present. Greatest of all was last summer's tercentenary celebration of Harvard University, signalizing the firm basis of intellectual freedom and leadership which is the prime requisite for a free people in a democracy.

Encouraged by the success of the Chicago Century of Progress and the Harvard Tercentenary, I venture to feature my address as signalizing an anniversary of the discovery of the electron. To be sure, it is only one generation old, and a generation is a sufficiently vague unit of time for my purposes. Yet, in spite of its youth, it bids fair to rival Chicago in its contributions to economic progress, and Harvard University in its contributions to the understanding of this world in which we live. So I venture to assert that no institution or community which has used one of these milestones to take stock of its achievements and plot its future course has stronger claims to intellectual significance and practical utility than I will claim for the electron.

The history of science abounds with instances when a new concept or discovery has led to tremendous advances into vast new fields of knowledge and art the very existence of which had hitherto been unsuspected. The discoveries of Galileo, Faraday, and Pasteur are such instances. But, to my notion, no such instance has been so dramatic as the discovery of the electron, the tiniest thing in the universe, which within one generation has transformed a stagnant science of physics, a descriptive science of chemistry, and a sterile science of astronomy into dynamically developing sciences fraught with intellectual adventure, interrelating interpretations and practical values.

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[1] Address of the retiring president of the American Association for the Advancement of Science, delivered at Atlantic City on December 28, 1936. Reprinted by permission from Nature, vol. 139, no. 3510, February 6, 1937.

I take particular pleasure in mentioning these practical values, for even the most unimaginative and short-sighted, hard-headed, "practical" business man is forced to admit the justification for the pure research—of no preconceived practical use whatsoever in the minds of those who led in its prosecution, and of all degrees of success and significance—which has been directed at the electron. For out of this research have come the following things which all can understand and appreciate: a growing business in manufacture of electronic devices which now amounts to 50 million dollars a year in America alone; a total business of some hundreds of millions of dollars a year which is made possible by these electronic devices; innumerable aids to health, safety, and convenience; and an immense advance in our knowledge of the universe in which we live.

THE BACKGROUND

In science, as in human affairs, great events do not occur without a background of development. The electron had an ancestry which can be traced back through the centuries. Its immediate progenitors were the electromagnetic theory of light, spectroscopy, and the leakage of electricity through gases. First cousins were X-rays and radioactivity and quantum theory, for, out of a background of long investigation of bewildering and apparently unrelated phenomena, there burst upon the scientific world the X-ray in 1895, radioactivity in 1896, and the electron in 1897—all while investigators in the older fields of heat radiation and thermodynamics were finding those bothersome inconsistencies in these hitherto respectable subjects which led to that unexpected extension of Newtonian mechanics now called quantum mechanics. The concept of the electron, behaving according to the laws of quantum mechanics, is now the basis of most of our interpretation of all that falls under the good old name of natural philosophy.

That only the pioneers of the scientific world were prepared for these discoveries, however, is witnessed by the fact that a standard textbook of chemistry widely used in my student days in 1904 stated that, "Atoms are the indivisible constitutents of molecules," and so late as 1911 a prominent physicist warned his colleagues not to be too hasty in accepting these new-fangled ideas.

The existence of electrons had been foreshadowed for a century by the facts of electrolysis, which led Davy and Berzelius to conclude that chemical forces were electrical in nature, and Faraday to conclude that electric charges exist only in multiples of some fundamental unit. For chemical acids and salts, dissolved in water, tend to split up into ions, that is, atoms or groups of atoms which move in an electric field in such directions as to indicate that they carry either positive or negative electric charges. Furthermore, it is found that the amounts of these ions which carry equal amounts of electricity are exactly proportional to the chemical combining weights of the ions. Faraday saw that this fact would be simply explained by assuming that every ion carries a charge proportional to its chemical valency, that is, the valency times a fundamental unit charge. But Faraday could not, from these facts, deduce the size of this unit of charge; he could only state the ratio of this charge to the mass of the chemical substance with which the charge was associated. Hydrogen, being the lightest of all ions, had of all known substances, therefore, the largest value of this ratio of charge to mass.

The first real evidence of particles of larger ratio of charge to mass than hydrogen ions came from the field of optics. Ever since Maxwell's equations of electromagnetism had predicted the existence of electromagnetic waves with the velocity of light, and Hertz, 17 years later, had discovered them experimentally, physicists had felt sure that light must be caused by some sort of oscillations of electricity within atoms. But only the vaguest and most unsatisfactory speculations, such as whirling vortices or pulsating spheres of electricity, had been suggested.

In 1896, however, Zeeman tried the experiment of examining the spectrum of a light source placed in a strong magnetic field, and discovered that the spectrum lines thus became split into components of slightly differing wave length, and that these components of the light showed characteristic types of polarization depending on the direction in which the light emerged from the magnetic field. Almost at once, in January 1897, Lorentz showed that this experiment proved that light is caused by the oscillation of electric charges, the motions of which are affected by the magnetic field in the manner required to explain Zeeman's experiments. This much was not unexpected, but what was startling was Lorentz's proof that the Zeeman effect could only have been produced by electrified particles whose ratio of charge to mass is nearly 2,000 times larger than that of a hydrogen ion, and whose mass is therefore presumably nearly 2,000 times lighter than hydrogen.

Almost at once this conclusion was confirmed in a more dramatic and understandable way by J. J. Thomson, the then youthful director of the Cavendish Laboratory. But let me first pick up this thread of the story a little farther back.

DISCOVERY OF THE ELECTRON

All through the 1880's and early 1890's a series of most striking and unexpected discoveries followed from investigations of electric arcs, sparks, and especially the glowing discharges of electricity at high voltages through glass tubes containing various gases at pressures far below atmospheric pressure. The striking color effects, mysterious luminous streamers and entirely bizarre behavior of these discharges made them the most popular, yet most elusive, subject of laboratory research of those days.

It was these phenomena which led Crookes to postulate the existence of a mysterious "fourth state of matter," different from the solid, liquid, or gaseous states. (Of course, we now know that Crookes's fourth state is simply the ionized state of matter.) Once, while attempting to photograph the appearance of a discharge at very low gas pressure, Crookes was bothered by the fact that all the photographic plates in the room with his apparatus became fogged, as if light-struck in spite of their opaque wrapping. He avoided the trouble afterwards, however, by keeping his new supply of plates in another room until, one at a time, they were wanted for use. Thus he solved an experimental difficulty, and missed making a great discovery.

At about the same time Röntgen, in Germany, was trying the same experiment, and he too was troubled by the fogging of his photographic plates. But, as the story goes, his laboratory assistant directed his attention to the peculiar fact that these fogged plates, when developed, showed the image of a bunch of keys which had accidentally been lying on top of the box of plates while the electric discharge experiments were in operation. Röntgen immediately looked into this and discovered that the fogging was due to penetrating radiations produced in the discharge tube where the cathode rays struck the target or anode. Thus by accident were X-rays discovered—that type of accident not uncommon in science when an observant experimenter is at work.

While on the subject of accidents, I might digress to tell of another accident which did not happen, also in connection with X-rays. For more than 15 years after their discovery, disputes raged as to whether X-rays were radiations, like light but of very short wave length, or electrically neutral particles of small mass and high speed. It was evident that they were not electrically charged, since their paths were unaffected by electric or magnetic fields. The leading advocate of the neutral particle theory was W. H. Bragg. In 1912, at Princeton, O. W. Richardson tried an experiment to see if X-rays could be refracted by a prism. A positive result would support the wave theory of X-rays. People had tried this with X-rays through glass prisms without success, but Richardson had an idea that an iron prism might be more effective. So he passed X-rays for hours and days through the tapering edge of a Gillette safety razor blade, but without finding any refraction. If he had happened to try the edge of a crystal instead of the edge of the razor blade, he would undoubtedly have discovered the peculiar diffraction of X-rays in passing through crystals, discovered a couple of years later by Laue, Friederich and Knipping and developed by father and son, W. H. and W. L. Bragg, which proved both the wave nature of X-rays and the atomic lattice structure of crystals. If Röntgen's discovery of X-rays was an accident, then I suppose Richardson's failure to discover diffraction of X-rays was a negative accident. I often wonder how many important negative accidents slip past us week by week!

But to get back on the subject of the electron: it was the cathode rays, which produce the X-rays, which finally turned out to be electrons traveling at high speeds. These cathode rays had been observed to shoot out in straight lines from the surfaces of cathodes in rarefied gases through which electric currents were forced by high voltage. Objects which they struck became luminous with fluorescent light, and objects in their paths cast shadows. But their true nature was disclosed when a magnet was placed near the discharge tube, for then their paths were curved in a direction showing that cathode rays were negatively charged. By measuring this curvature produced by a magnetic field of known strength, and making a pretty sure assumption that the kinetic energy of these rays was determined by the voltage applied to the tube, J. J. Thomson in 1897 first showed that cathode rays are negatively charged particles with a ratio of charge to mass nearly 2,000 times that of hydrogen. He furthermore showed that these particles are of the same type, as regards ratio of charge to mass, from whatever gas or cathode material they are produced. He therefore announced these particles, which he called "corpuscles," to be universal constituents of all substances. Thus was the electron discovered.

MASS AND CHARGE OF THE ELECTRON

Quick and fast came experiments of ingenious design to study the electrons more accurately. They were pulled this way and that by electric and magnetic fields. They were caught in miniature metal fly-traps, called Faraday cages, to measure their charge and kinetic energy. They were detected in their paths electrically, or by photographic plates or by fluorescence. Continually refined from that day to this, we now know that an electron has a ratio of charge to mass which is about 1,842 times the similar ratio for a hydrogen atomic ion.

It was also very desirable to know separately the charge and the mass of an electron, and not just the ratio between these quantities. So an even more interesting lot of experiments has been carried on to measure the electron's charge. They were begun in about 1900 by J. J. Thomson and his colleagues, Townsend, H. A. Wilson, and C. T. R. Wilson. I think a brief résumé of attempts to measure the electron's charge will throw an interesting sidelight on the versatility of scientific attack on a difficult problem.

The first attempts were by Townsend, by measurements on the motion and electrification of fog produced when electrolytic gas was bubbled into a region of air which was slightly supersaturated with water vapor, but too many uncertainties were involved to make this work convincing. The first accepted results were by J. J. Thomson, who, after an earlier attempt, employed a technique of producing fog under controlled conditions, developed by his colleague, C. T. R. Wilson, whose method was refined further by his pupil, H. A. Wilson.

It had long been known that water droplets of fog do not form in air which is somewhat supersaturated with water vapor unless there are nuclei, like specks of dust, on which the moisture can condense. Later, Townsend found that fog will also condense on ions, and more readily on negative than on positive ions. C. T. R. Wilson designed an apparatus in which dust-free air could be supersaturated with moisture sufficiently to permit condensation of fog droplets on negative but not on positive ions, which were produced by some convenient ionizing agent. So a fog was formed, in which each droplet of water was condensed on a negative ion. Thomson employed this apparatus in the following manner.

Of course, this fog gradually settled downward under the pull of gravity—slowly because the drops were small compared with the viscous resistance of the air through which they fell. It was like the slow settling of dust on the furniture and floor of a room. But the theory of the rate at which spheres move when a force drives them through a viscous medium was already well known, owing to Stokes's law. From this law, measurement of the rate of fall of the fog in centimeters per second as measured by a little telescope focused on the top edge of the fog, combined with knowledge of the force of gravity and the viscosity of air, enabled Thomson to calculate the size of the individual fog droplets. Dividing the total amount of water in the fog by the amount in one drop gave him the total number of fog droplets, and therefore the total number of negative ions. H. A. Wilson added the refinement of superposing an electric field on the gravitational field which pulled the drops through the air. Then, as the fog settled to the bottom of the apparatus, it deposited its electric charge, which altogether, was large enough to be measured with an electrometer. So, dividing this total charge by the number of ions composing it gave, as the charge of one ion, 3.4×10^{-10} electrostatic units. This was the first real measurement of the charge of an electron, and was the value quoted in the tables of physical constants when I became a graduate student in 1910.

About that time Millikan, who has always had a flair for picking strategically important subjects to which to devote his investigative talents, undertook with his students a revaluation of the electronic charge. Sources of error in the fog method were well recognized: Fog droplets were not all the same size, though measurements could only be made on those smallest ones which fell most slowly; also droplets did not remain of constant size, smaller ones tending to evaporate and larger ones to grow; also there were unavoidable convection currents in the air which modified the rate of fall of the fog; and some droplets might contain more than one ion.

Millikan cleverly avoided or minimized these difficulties by using only a single droplet of some relatively nonvolatile liquid like oil or mercury. By ionizing the surrounding air in an electric field he could put various electric charges on the drop. Illuminating it by a powerful light and viewing it like a star through a measuring telescope, he could measure its rate of fall under gravity and its rate of rise when pulled upward against gravity by an electric field, and keep repeating these observations for hours. These measurements were so precise that, to keep pace with them, he had to measure the viscosity of air with hitherto unequalled accuracy. When all this was done, he had proved conclusively that all electric charges are integral multiples of a fundamental unit charge, the electron, the value of which he set as 4.774×10^{-10} electrostatic units—about 40 percent larger than the earlier estimates and believed by Millikan to be correct within one part in a thousand.

Within the past half-dozen years, however, doubt has been thrown on the estimated accuracy of this value from quite a different direction, in work with X-rays. Originally, X-ray diffraction experiments in crystals proved the geometric arrangement of atoms in the crystals, but did not establish the scale of distances between atoms or the X-ray wave length. These distances, once the arrangement of atoms was known, were calculated from absolute values of the weights of the atoms, which in turn were derived from electrochemical equivalents and the value of the electronic charge. Thus X-ray wave lengths, masses of atoms and distances between atoms in crystals all had values dependent on knowledge of the charge of the electron.

Recently, however, A. H. Compton, Bearden, and others have succeeded in making measurements of X-ray wave lengths by diffracting X-rays from a grating ruled with 15,000–30,000 parallel fine lines to the inch, and operating near the angle of grazing incidence. These measurements involve only knowledge of the number of lines per inch on the grating, and the angles of incidence and diffraction of the X-rays—both depending only on measurements of length and capable of high precision. X-ray wave lengths thus measured were a little different from the earlier accepted values, and this cast doubt on the accuracy of the electron charge value which had been used in the earlier X-ray estimates. The difference was not large, only about 1 part in 200, but it meant either that experiments had not been as accurate as believed or that there was some unrecognized complicating factor.

So Millikan's work has been repeated in various laboratories with refinements, such as the use of a remarkably nonvolatile oil for the drop. But the chief error was found to lie in the measurements of the viscosity of air. During the past year Kelletrop, of Uppsala, has thus published a revised "oil-drop" determination of electronic charge as 4.800×10^{-10} E. S. U., which is in excellent agreement with the "X-ray" determinations. Bearden has just presented his own confirmation of this agreement before the American Physical Society.

It is an interesting coincidence that this best value of the charge of the electron is exactly the same as the figure given by Rutherford 30 years ago, though then determined with so much less precision that not much confidence was placed in it, except as to order of magnitude. It was then known that the alpha rays from radium are helium atoms which have lost two electrons and are therefore doubly positively charged. Rutherford caught a lot of these alpha rays in a metal trap, measuring their aggregate electric charge with an electroscope, and counting them by the scintillations which they produced on striking a fluorescent screen or otherwise. Dividing the total charge by the number gave him double the electronic charge, which he thus calculated to be 4.8×10^{-10} E. S. U. Already knowing the ratio of charge to mass with high precision, this value of the charge enables us to fix the electron's mass as 9.051×10^{-28} grams.

ELECTROMAGNETIC MASS

When we speak of the mass of an electron, however, we enter a whole new field of ideas. Some years before the discovery of electrons, J. J. Thomson had pointed out that an electrified particle will possess inertia, that is, mass, simply in virtue of its charge alone, irrespective of whether or not it has any mass of the gravitational type which we have been accustomed to think of. This "electromagnetic" mass comes about from the fact that any mechanical energy which is expended in accelerating an electric charge is transformed into the energy of the magnetic field surrounding the electrified particle in virtue of its motion. In fact, the kinetic energy of a moving electric charge is found to be simply the energy of its magnetic field and depends only on the square of the velocity of the charge, the amount of charge and the geometrical shape of the charge.

Making the simplest possible assumptions about the shape of an electron, such as a solid sphere or a hollow spherical shell of electricity, and assuming all its mass to be of electromagnetic origin, the diameter of an electron was calculated to be of the order of 10^{-13} cm. It must be emphasized, however, that this estimate of size is not, like the charge and mass, a definite measurement, but is simply an estimate based on assumptions, at least one of which is quite uncertain. For while we have both logic and experiment to back up the assumption that all the mass of the electron is of this electromagnetic origin, we must confess to utter ignorance regarding the shape of the electron. Indeed, some facts suggest that it may have different sizes and shapes in different environments, as in the free state or in an orbit of an atom or in the nucleus of an atom. So our estimate of 10^{-13} cm for the size of the electron is, at best, very crude.

The idea of electromagnetic mass was strongly supported by the fact that measurements of the mass of very fast moving electrons, through measurements of the ratio of charge to mass of beta rays from radium or cathode rays in high-voltage discharge tubes, showed that their mass is not really a constant thing but increases with the speed of the electron. The value of electron mass given above applies, strictly speaking, only to an electron at rest. Practically, however, it is accurate enough for practical purposes for electron speeds below about one-tenth the speed of light. At this speed the electron's mass is about half of one percent larger than if it were at rest. At still higher speeds, the mass increases more and more rapidly, approaching infinite mass as the speed of light is approached.

These facts, experimentally determined, were shown by Abraham to be of the type expected if the entire mass of an electron is of electromagnetic origin, due entirely to its electric charge. It was this argument, which has since received confirmation from other directions, which was the basis of the theory that all mass, that is, all matter, is electrical. However, the simple electromagnetic concepts were not quite adequate to give an accurate quantitative interpretation of these experiments, and it required the additional introduction by Lorentz of the concepts of the special theory of relativity to bring about complete interpretation of the experiments.

THE ELECTRON AND QUANTUM THEORY

Just two things more do we know accurately about the properties of electrons, in addition to their charge and mass. We know that they are also tiny magnets of strength equal to the basic unit of magnetic moment generally called the Bohr magneton. Once the electron had been discovered, it became natural to seek in it also the explanation of magnetic phenomena, since it was only necessary to assume that the electricity of an electron is whirling about an axis, and the electron becomes endowed with the properties of a tiny magnet. Parsons, Webster, and others examined the possibilities inherent in various assumed configurations, with interesting results. But it was only with the introduction of the quantum theory for the interpretation of atomic structure and spectra that the magnetic character of the electron has, within the last dozen years, been put on a well-established basis.

The other thing we know is perhaps the most unexpected of all the electron's properties—it behaves like a wave when it collides with other objects. Davisson and Germer discovered this in the Bell Laboratories, while examining the way in which a beam of electrons, incident on a solid surface, was scattered or reflected by it. They found, if the surface were crystalline, that the electrons were scattered just like diffracted X-rays, but that, unlike X-rays, the wave length of an electron is not fixed but varies inversely as its speed. J. J. Thomson's son, G. P. Thomson, has made very illuminating studies of this phenomenon, which is the inverse of the Compton effect; together they have given physicists two mottoes: "Particles behave like waves and waves behave like particles" and "Here's to the electron; long may she wave." One of the triumphs of the new wave mechanics (a brand of quantum mechanics) is that it offers a medium of explanation of these strange phenomena. But my subject of the electron is too long to let me attempt a digression on wave mechanics.

SIGNIFICANCE OF THE ELECTRON CONCEPT

With this sketch of the electron itself before us, let us turn to some of the more important directions in which the electron has given us an interpretation of the physical universe generally. Immediately were explained the phenomena of electrolysis and of ionization generally, for ions were simply atoms or groups of atoms which had gained or lost one or more electrons. Primary chemical forces were explained as the electrostatic attraction between atomic groups which, respectively, contained an excess or a deficiency of electrons. (The more refined interpretation of chemical forces within the past half-dozen years, by Pauling and Slater, has been based upon the quantum theory of atomic structure.)

The three types of rays from radioactive substances were interpreted: alpha rays as helium atoms which had lost two electrons; beta rays as electrons; and gamma rays as X-ray-like radiations. In fact, Becquerel showed the magnetic deflection of beta rays in the same year, 1897, that Thomson showed the magnetic deflection of cathode rays and interpreted them as electrons.

For many years two unexplained phenomena had been studied in metals. When highly heated or when illuminated by ultraviolet light, metals had been shown to emit negative electricity. It was the work of but a year, after the discovery of the electron, for J. J. Thomson and his pupils to show that both these phenomena consist in the emission of electrons. But by what mechanisms are they thus emitted?

That was a question the study of which has led to most important theoretical and practical consequences.

Richardson, first as a pupil of Thomson and then as a professor at Princeton in the early 1900's, developed the theory of thermionic emission of electrons, according to which the electrons are evaporated from the surface of a metal at high temperatures by a process very analogous to evaporation of molecules. The electrons are assumed to have the same distribution of kinetic energies that molecules possess at the same temperature in accordance with the principles of kinetic theory. They escape from the surface, if they reach it, with enough energy to take them away in spite of the attraction tending to pull the electron back into the metal. This attraction is expressed in terms of the now famous "work-function," a sort of latent heat of evaporation of electrons, which is the work that must be done to get an electron clear of the surface. With these simple assumptions, an equation was derived for the rate of emission of electricity as a function of temperature which has stood the test of perhaps as wide a range of experimentation as any other equation of physics, a range of values of more than a million-million fold in current without any detectable departure from the theory, if this is properly applied.

Richardson's measurements of the "work-functions" of various metals showed that these values run closely parallel with one of the longest known but least understood properties of metals, namely, their contact potential properties. By contact difference of potential is meant the voltage difference between the surfaces of two metals when they are placed in contact. Richardson found that the difference between the "work-function" of two metals was, within the limits of accuracy of the data, the same as their contact difference of potential. He therefore proposed the theory that the contact potential property of a metal is determined simply by the work necessary to remove an electron from its surface.

As a beginning graduate student under Richardson in 1910, I was given the job of undertaking a test of this theory through experiments on the other electron-emitting phenomenon, the photoelectric effect. Einstein a few years before had proposed his famous photoelectric equation, which was a contribution to physical theory certainly comparable in importance and thus far more useful in its applications than his more impressive and wider publicized general theory of relativity. According to it, an electron in a metal may receive from the incident light an amount of energy proportional to the frequency of the light—to be exact, an energy equal to Planck's constant h times the frequency ν. If it escapes from the metal, it must do an amount of work w to get away, so that its kinetic energy after escape from the metal would be the difference $h\nu - w$. Obviously, by measuring these kinetic energies of electrons liberated from various metals by light of various frequencies, it should be possible to find out if the "work-functions" w of different metals are indeed related to their contact differences of potential in the manner predicted by Richardson's theory.

In two papers, by me in 1911 and jointly with Richardson in 1912, it was concluded first that the contact differences of potential are related to the "work-functions" as Richardson had predicted, and secondly that Einstein's photoelectric equation, rather than a rival theory then under discussion, properly described the facts. Practically simultaneously with this second paper, there appeared the report of a similar verification of Einstein's equation by A. L. Hughes, then in England, though lacking the quantitative connection with contact differences of potential.

This early work was not very accurate, partly because of lack of good vacuum technique for maintaining untarnished surfaces in a vacuum, partly through lack of constant sources of ultraviolet light and partly because the ultraviolet spectrographs used to isolate the various wave lengths of light gave a certain spectral impurity of scattered light of other wave lengths. These sources of error were recognized but not overcome when Millikan, in 1916, made a striking advance by using doubly purified light or otherwise correcting for the effects of impurity, and secured a verification of Einstein's equation which was far more accurate than the earlier work as regards the value of Planck's constant h. In fact, Millikan's work remains to this day as one of the best determinations of this important constant. In regard to the "work-function," however, this work of Millikan's was not so successful, for, after having apparently discovered facts at variance with Richardson's interpretation of the equation and its relation to contact potentials, these differences were ultimately found to reside in faults of experimental procedure or interpretation, so that Richardson's interpretation of Einstein's equation still holds.

In both thermionic and photoelectric effects, theoretical refinements have been introduced by the recent quantum mechanics, and great advances made in experimental technique. However, it is fair to say that their interpretations on the electron theory have been among the major achievements of this theory.

CONDUCTION OF METALS

While we are on the subject of electricity in metals, what constitutes the phenomenon of easy flow of electricity that is the distinguishing feature of metals? J. J. Thomson at once suggested that this must be due to the existence in metals of electrons free from their parent atoms, moving freely, except for collisions, whenever an electric field was applied in the metal. The theory thus worked out was attractive, but it encountered inconsistencies. There was not even any real evidence that electricity in metals was conducted by electrons.

Then along came Tolman with one of his brilliant ideas, skilfully followed by experiment. It had earlier been suggested that, whatever are the carriers of electric current in metals, it should be possible to centrifuge them toward the periphery of a disk if this were rotated very rapidly about its axis. To be more specific, if electrons are free to move in metals and if a wire connects the center and the periphery of the rotating disk through lightly pressing brush contacts, electrons should be thrown out of the disk at its periphery and pass back into the center of the disk through the wire. It would be rather analogous to a current of water driven by a centrifugal pump through a pipe circuit. But all attempts to detect such currents proved futile, because the currents produced by the friction of the contact against the periphery were far larger than the currents to be expected from the centrifuging of electrons.

But Tolman devised two methods of giving powerful accelerations to metal conductors in such manner that he was able to measure the feeble electric currents that were produced as the carriers of electricity in the metal were shaken back and forth, and his calculations showed that these currents were indeed of the size to be expected if the current is carried by electrons. This is our direct evidence that electrons carry the electric current in metals. The mechanism by which they do this is now beginning to be disclosed by Slater, on the basis of an application of quantum mechanics and spectroscopic ideas to metals, and again is an example of the refining power of the quantum theory to succeed where older classical theory was gropingly suggestive, but inadequate.

STRUCTURE OF THE ATOM

Now that I come to the most basic of all the phenomena which the electron has been called upon to interpret, I almost lose courage, for the subject is too vast and complex for anything but encyclopaedic treatment. I refer to the structure of atoms. Previous to the discovery of the electron, literally nothing was known of the internal structure or composition of atoms. With this discovery, however, it immediately became evident that all atoms contain electrons and an equivalent amount of positive electricity in some form. It was again J. J. Thomson's genius which began the investigation of the inner atom. This was only about 25 years ago.

Thomson reasoned that, if X-rays were made to fall on any substance, the electrons in the atoms of the substance would be forced to vibrate back and forth by the powerful alternating electric forces in the X-ray waves. But, in thus vibrating back and forth, these electrons would re-radiate secondary X-rays in all directions. He calculated just what fraction of the original X-ray energy ought to be thus re-radiated by each electron, and then set his pupils to measure just what this fraction was in specific cases. From the experimental results he was thus able to calculate the number of electrons which performed the re-radiation in each case. These results indicated that the number of such acting electrons in each atom was about half the value of the chemical atomic weight of the atom. Thus first were counted the electrons in an atom.

Rutherford and his pupils, aided by the mathematical analysis of Darwin, tackled the problem from a different point of view. They studied the distribution of deflection of alpha particles, shot out of radioactive materials, as these alpha particles traversed thin sheets of solid materials. They found that this distribution was quantitatively what would be expected if the deflections were produced by ordinary electrostatic forces, varying as the square of the distance, between the alpha particle and a very small object containing most of the mass in each atom. They were thus able to show that this small object is not more than one ten-thousandth of the diameter of the atom, that it contained substantially all the mass of the atom and that it carried a positive electric charge equal, in electronic units, to about half the chemical atomic weight of the atom.

Thus arose the concept that the atom is composed of a positive nucleus of small dimensions, surrounded by electrons to the number of about half the atomic weight.

This had scarcely become established when it was brilliantly refined and extended by Moseley, just before he went to his untimely death in the Great War in 1914. Moseley had made a most ingenious study of the spectra of X-rays of a large number of the chemical elements, using a modification of the X-ray spectroscopy technique developed by the Braggs. He found that the square roots of the frequencies of the characteristic X-ray lines were numerically very simply related to the number which gave the place of the element in the periodic table of the elements, so useful to chemists but so entirely without explanation. Thus this number acquired a definite physical significance and is now well known as the "atomic number."

For all the elements heavier than hydrogen, this atomic number is about half the atomic weight and, to make a long story short, this atomic number turns out to be exactly the number of electronic units of charge on an atomic nucleus, or the number of electrons in the atom outside the nucleus. At the same time, Moseley's work proved to be one of the greatest advances ever made in the basic interpretive side of chemistry.

Now that the number of electrons in each atom was known, the next step was to wonder how they were arranged, what held them in place and what they were doing in their spare time. Suggestions were not slow in coming. In fact, even before Moseley's work, two rival theories had appeared, one devised by chemist Lewis and extended by Langmuir to explain the directional symmetries of atoms as indicated by their molecular combining forms, and the other devised by physicist Bohr to account for spectra. Gradually the Bohr theory has been developed to include the symmetries of the Lewis-Langmuir theory, so that both may be said to be merged, with many major additions too numerous to mention.

It was Bohr's bold genius to cast off some of the fetters of classical mechanics, which had been fairly well proved inadequate to meet the situation, and to devise a new mechanics frankly to meet the simplest known facts of atomic structure and spectroscopy—the hydrogen atom and the atomic hydrogen spectrum. In doing so, he at one stroke brought into the same picture the quantum theory of radiation, the electronic structure of the atom and the facts of spectroscopy. He had his electron moving in a circular orbit around the nucleus under the regular laws of electrostatic attraction and centrifugal force. But he stipulated that only such orbits were possible in which the angular momentum of the electron was an integral multiple of Planck's constant h divided by 2π. He also stipulated that the electrons should not radiate energy while revolving in their orbits, but only when they jumped from one orbit to another. In this case the frequency of light radiated was equal to the change of energy of the electron between the two orbits, divided by Planck's constant h. With these assumptions, the spectra of hydrogen and of ionized helium were quantitatively explained in their main features, but not in their finer details.

Then came the Great War, and we heard little of atomic structure in the United States. But in Germany, Sommerfeld was extending Bohr's ideas in most interesting ways. He showed that, by considering elliptic as well as circular orbits, and taking account of the variation of the electron's mass with speed, the fine details as well as the main features in the spectra of hydrogen and ionized helium were accurately explained. He also showed how the theory could be extended to deal with atoms where there were many electrons moving in orbits. He showed that these additional concepts were in the right direction to explain the more complicated spectra both in the visible and in the X-ray regions.

SPECTRAL LINES

When this new work first was known in America, it started the most feverish and earnest scientific activity that the country has ever known, which is still in progress with undiminished zeal and with increasing productive effectiveness. I well remember when the first copy of Sommerfeld's Atombau und Spectrallinen came to America in the possession of Prof. P. W. Bridgman. Until later copies arrived, he knew no peace and enjoyed no privacy, for he was besieged by friends wanting to read the book—which he would not allow to go out of his possession. I recall, too, the sudden popularity of the only two or three men in America who knew what a spectral series was. Heretofore, practically our only interest in spectra had been in the culinary variety of spectroscopy used by chemists in identifying chemical elements. No interpretive quality to speak of had hitherto been attached to the peculiar numerical regularities which had been discovered in the vibration frequencies of groups of spectrum lines.

I recall, too, the dismay with which we found only a handful of mathematical physicists versed in the analytical dynamics underlying the new atomic structure theories. In the summer of 1921, having been taught by one of these few mathematical physicists, I went to the University of Michigan to lecture on Sommerfeld's theory, and found there also F. A. Saunders, invited to impart his knowledge of spectrum series. In the winter of 1926, Born and Jordan having just announced a new development in quantum mechanics, I found more than 20 Americans in Göttingen at this fount of quantum wisdom. A year later they were at Zurich, with Schrödinger. A couple of years later, Heisenberg at Leipzig and then Dirac at Cambridge held the Elijah mantle of quantum theory. In America, contributions are coming rapidly, particularly in the fields of application to chemical interpretations, metals and other complex situations.

From all this has come the situation which permitted Dirac, a few years ago, to write: "The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known, and the difficulty is only that the exact application of these laws leads to equations much too complicated to be soluble." But if any ambitious young scientist be discouraged lest there be little left to do, let him consider the unexplored atomic nucleus, or the fact that every attempt to apply these laws, which look so satisfactory to us now, discloses new realms of knowledge still unexplored.

Time forbids mention of the most interesting work which was done to check and extend the theories of atomic structure, through direct measurement of the energy states of atoms and molecules by carefully controlled bombardment of these molecules by electrons. Begun by Franck and Hertz in Germany, much of this work was done in America by Foote and Mohler at the Bureau of Standards, by my students at Princeton and by Tate's group at Minnesota, all since 1920.

Before leaving the interpretive triumphs of the electron, however, I cannot refrain from jumping from the atom to the universe, to the interpretation of conditions on the stars. Spectra of stars had long been known, and these were interpreted as indicating that some stars consist principally of hydrogen, others of helium and others of many chemical elements like our sun. But in 1922, a young Indian physicist, Meghnad Saha, first applied atomic structure theory and knowledge of ionizing potentials to the sun and stars. He considered ionization in the hot vapors of the stars to be like a chemical dissociation produced by heat, in which the products of dissociation are electrons and the positive ionic residues of the atoms, and in which the heats of dissociation are given by the ionizing potentials of the atoms. In this way was developed a rational quantitative interpretation of stellar spectra which has thrown enormous light on the problem of conditions of temperature, pressure and condition of the chemical elements in stars. Russell in America and Milne in England have ably applied and extended this theory.

THE ELECTRON IN INDUSTRY

Finally, I come to the last phase of my subject, the social significance of the electron. By this I mean, of course, its useful applications. The first of these was Edison's invention of a thermionic rectifier, based on his discovery that negative electricity would flow across a vacuum from a hot filament to an adjacent electrode, but would not flow in the opposite direction. This was some years before the electron was discovered as the responsible agent in this phenomenon. But within a few years after the discovery of the electron, Fleming had shown that this same device will operate to rectify radio wave impulses, and thus permit their detection with a sensitive direct-current instrument. From this was patented the Fleming valve.

Once the basic character of thermionic emission was understood, and spurred on by the opportunities opening up in the radio field, new inventions, improvements, and applications of thermionic devices came rapidly. Of major importance was the three-electrode tube amplifier of De Forest. Industrial research laboratories in the communications and electric manufacturing business took the lead in developing techniques and in penetrating scientific exploration. Noteworthy were the vacuum techniques and the monomolecular layers of activating materials developed by Langmuir and the high-vacuum thermionic X-ray tube of Coolidge. In the Bell Laboratories, oxide-coated filament tubes of good performance were developed and applied particularly to use in long-distance telephony. Let me give just two illustrations of the marvelous powers of some of these instruments.

It has been calculated that the energy of a trans-Atlantic radio signal caught by the receiving station in Newfoundland comes in at about the rate required to lift a fly 7 inches in a year.

What is the largest number that has any physical significance? This is impossible to answer, being largely a matter of definition. But one common answer to this is 10^{110}, or one followed by 110 ciphers. This is about the number of electrons (the smallest things known) which would be required to fill up the universe to the greatest distances discovered by astronomy, if the electrons could be imagined to be closely packed side by side to fill up this whole space. Yet this number, large as it is, is very small indeed compared with the aggregate factor by which the energy of a voice striking a telephone transmitter in San Francisco is amplified by electronic tubes in the process of a long-distance telephone conversation to London. This amplification factor is about 10^{256}, or unity followed by 256 ciphers. If the universe were multiplied in size by the number of times it is larger than an electron, it could still not hold as many electrons as the number of this telephone amplification factor.

Then, mostly within 10 years or so, has come an active introduction of thermionic devices which are not highly evacuated, but operate with supplementary action of intense ionization of the gas in the tube. First of these were the low-voltage arc rectifiers, like the tungar. Most interesting and versatile are the thyratrons, which permit easy control of powerful currents and machinery, and give a new means of converting alternating into direct current, or vice versa. In this group also are some of the new types of lamps, of high efficiency or special color.

Not so striking, but equally interesting, have been the useful applications of the photoelectric effect. First was the use of sensitive photoelectric cells to replace the eye or photographic plate in astronomical telescopes. Then came sunshine meters, devices to open doors or count people or sort merchandise automatically, or to register the speed and license number of the unwary autoist. Most important thus far are the current-producing mechanisms in the sound-movie apparatus and in television equipment.

While, commercially, radio, sound movies, and long-distance telephony are at present of greatest importance, of no less importance, especially to us as scientists, are the marvelous tools which have been put into our hands for further research in practically every field of science, from physics and chemistry to psychology and criminology.

So we see how, within one generation, the electron has been discovered and examined, with its aid our intellectual outlook upon the universe has expanded in content and simplified in basic concept, and in its use mankind has the most versatile tool ever utilized. The end of the story is far from told. Every fact or relationship of the electron appears fuzzy with uncertainties when closely examined, for it can truly be said that every discovery discloses a dozen new problems. The field of practical and commercial uses of electronic devices is certainly still largely in its early stages of exploration.

This story illustrates in vivid manner a number of characteristics of scientific work, some of which I shall simply enumerate: (1) progress comes by spurts of advance as some big new idea opens up new territory, alternating with periods of consolidation; (2) progress comes not by revolution or discarding of past knowledge and experience, but is built upon past experience and is its natural extension once the vision from new vantage points is secured; (3) there is nothing so practical in its values as accurate knowledge, and the pursuit of such knowledge has been most successful when not fettered with the initial demand that it be directed toward practical ends.

I would not give the impression that it is only the electron which has given new life to modern physical science. A story of similar interest could be built around the new concepts of radiation and atomic energy as expressed in the quantum theory, or about the electron's big brother, the proton, or his rather nondescript cousin, the neutron. In the atomic nucleus is a field of further exploration of enormous promise, now only beginning to be opened up by use of radioactive materials, cyclatrons and high-voltage generators.

Although these things have happened very recently, no one has better described the process and intellectual value of this type of scientific research than did Aristotle in the quotation which is inscribed in Greek on the facade of the National Academy of Sciences building in Washington:

> The search for truth is in one way hard and in another easy, for it is evident that no one can master it fully nor miss it wholly. But each adds a little to our knowledge of Nature, and from all the facts assembled there arises a certain grandeur.

PHOTOGRAPHY BY POLARIZED LIGHT[1]

By J. W. McFarlane

[With 6 plates]

We are blind to some of the most beautiful phenomena in the domain of light. Our eyes respond naturally to differences in color and in intensity of light, and it is by these differences that we are able to see the world around us. There is another property in which light rays may differ, but our eyes, unaided, cannot see those differences. This property is called polarization, and is concerned with the manner in which the light ray vibrates. Were we able to see unaided these differences in polarization, we would be conscious of a dark wide band across the sky, normally invisible. We would also see oblique reflections darken, and we would see beautiful color effects in some common transparent materials.

WHAT IS POLARIZED LIGHT?

While the nature of light is not entirely understood, many of its effects can be explained by assuming that light is a vibratory motion which goes through space in the form of waves. Among these effects is the polarization of light. The vibration of a light wave is not along the direction of the ray, as in the case of sound, but is at right angles to the ray and usually in all possible directions, that is, up and down, sideways, etc. It is possible (by various devices generally known as polarizers) to change the light ray so that only one direction of vibration is left. The ray is then said to be polarized, or strictly speaking, plane-polarized.

A number of polarizing devices have been known to scientific workers for many years, but they have involved the use of prisms having a very small field and unsuited to photography. The invention which makes the Pola-screen possible is a polarizing substance in sheet form containing countless minute, rodlike crystals which are parallel to each other. The Eastman Pola-screen type I incorporates this sheet material cemented between glass plates.

The vibration plane of the polarizer is parallel to the vibration of the emerging rays. In the Pola-screen, the direction of the vibration plane is given by the engraved line on the indicator handle. In figure 1 ordinary light is coming from the left. It is vibrating in all directions. It then passes through the polarizer at the left, the vibration plane of which happens to be vertical. The ray is polarized, vibrating in a vertical plane only. If this polarizer had been placed with its vibration plane horizontal, then the rays would vibrate in a horizontal plane.

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[1] Reprinted by permission from the American Annual of Photography, 1937.

If a second polarizer is placed in the path of light which has left the first polarizer, another interesting property is brought out. If the vibration plane of the second polarizer is parallel to that of the first, the ray is transmitted freely, still vibrating in the same plane, as shown in the upper drawing of figure 1. The polarizers are then said to be *parallel*. But if the second polarizer is rotated, the intensity of the light is gradually cut down, and when the vibration planes of the two polarizers are at right angles, as in the lowest drawing of figure 1, practically no light is allowed through. The polarizers are then said to be *crossed*.

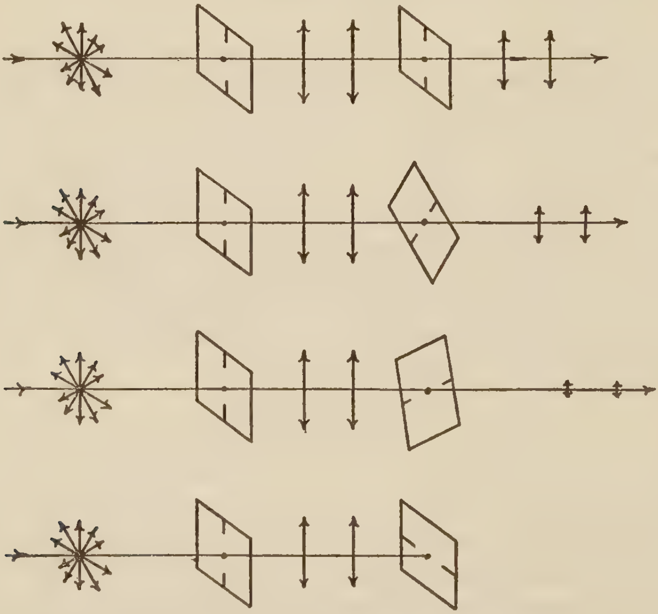


FIGURE 1.—Light rays are polarized by the Pola-screen at the left, the vibration plane of which is shown vertically. The amount of light let through by the second Pola-screen is cut down as the Pola-screen is turned. When the vibration plane of the second Pola-screen is at right angles to the first, practically no oblique light gets through.

These properties are summarized in terms of a Pola-screen thus:

1. Light transmitted by a Pola-screen vibrates in a direction parallel to the indicator handle.
2. This direction of vibration rotates as the Pola-screen is rotated.

3. Light already polarized will pass through a Pola-screen most freely if the ray is vibrating parallel to the indicator handle.

4. Light already polarized, which vibrates at right angles to the indicator handle, will not pass through a Pola-screen.

We can appreciate these peculiar properties, if we arrange two Pola-screens together, as in plate 1, so that the vibration planes are parallel, as indicated when their handles are parallel to each other; we see that light is transmitted freely. If one Pola-screen is turned so that its handle is at right angles to the other, practically no light is transmitted.

THE SOURCES OF POLARIZED LIGHT

It is now evident that we have a tool possessing unique possibilities in controlling light. As the photographer is very much concerned in controlling light, this is naturally interesting to him. The value of this new device lies in the fact that there are two sources of polarized light in nature: (1) Ordinary, unpolarized light, specularly reflected from any nonmetallic surface at about 32°–37° to the surface, is strongly polarized by the act of reflection, as shown in figure 2. There is some effect at other angles, but none at 0° or 90°. (2) The light from a blue sky, which comes from the region at right angles to the sun's rays, is strongly polarized, as shown in figure 3.

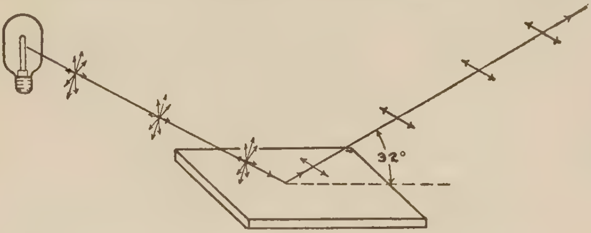


Figure 2.—Ray polarized by reflection. A ray of ordinary, unpolarized light is almost completely polarized when specularly reflected at about 32° to any nonmetallic surface, such as glass. This permits subduing oblique reflections from glass and water by a single Pola-screen over the lens.

POLA-SCREEN AT THE LENS ALONE

Since light rays which are reflected obliquely are polarized, they can be stopped with a Pola-screen, and we can photograph obliquely through glass or water in such a way that we subdue the surface reflections to show detail beyond. The light from the detail beyond the surface is, in general, not polarized, and therefore will be transmitted by the Pola-screen at the lens which at the same time will stop the light reflected at the surface.

OBLIQUE REFLECTION CONTROL

This property has direct application to photographing store windows where their design is such that an oblique picture is desirable, as shown in plate 2.

The photography of floorings is another sphere of usefulness. The reflection of windows and light colored walls are frequently troublesome. The pattern in linoleum floors and the grain in wood floors, as shown in plate 3, can be brought out in a very striking manner. It so happens that the angle normally used by the photographer in photographing a floor or floor covering is such that the Pola-screen is very effective.

The Pola-screen has a number of applications in architectural photography. It occasionally happens that a building is to be photographed late in the day, and an undesirably bright oblique reflection from the low sun partially hides detail in an exterior wall. The Pola-screen can subdue this reflection to show the detail desired. Reflections from tile and slate roofs can frequently be subdued as desired.

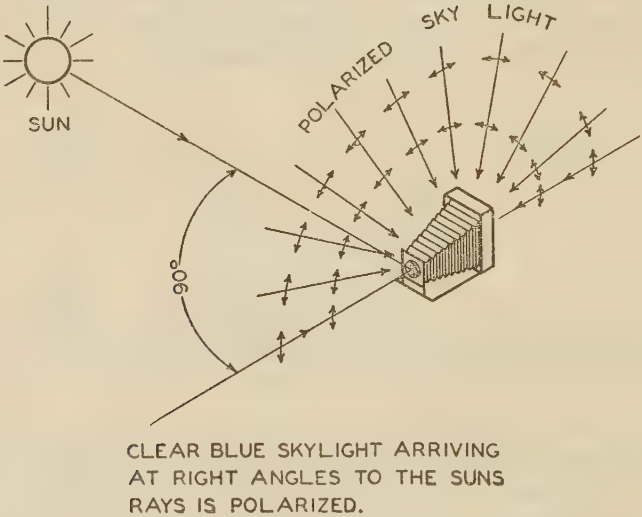


FIGURE 3.—The sky may be darkened by the Pola-screen without affecting the monochrome rendering of foreground objects. The strongest effect is attained with the camera axis roughly at right angles to the sun's rays.

Another application concerned with oblique reflections is in subduing reflections which are distracting or harmful to best composition. In photographing motor cars, it is generally desired to subdue to some extent the glossy reflection from the sides and tops. As the motor car is frequently photographed at an angle to the camera axis, considerable control of such reflections is possible (pl. 4).

So far we have considered only oblique reflections over which control can be exercised with a single Pola-screen at the lens. To summarize—while many reflections are desirable because they reveal texture, form, and position of objects, reflections should be and can be avoided in the following cases, if a single Pola-screen is used at the lens: (1) Photographing obliquely through glass or water; (2) photographing a surface the detail of which is obscured by oblique reflections; (3) photographing where bright oblique reflections interfere with good composition. All these cases of oblique reflection control apply to nonmetallic surfaces.

SKY CORRECTION

Controlling the brightness of the sky is another field of usefulness of the Pola-screen as mentioned before. There is a band in the sky from which the light is strongly polarized. This band is at right angles to the sun's rays, as shown diagrammatically in figure 3. If we imagine the line from ourselves to the sun as an axle, this band forms a wheel in the sky around this axle, with us at its center. Therefore, at sunrise the band is north, overhead, south; at noon, near the horizon in all directions; and at sunset, north, overhead, south again. The band swings from overhead west during the morning, from east to overhead in the afternoon, passing through every part of the sky. The band is sufficiently wide to provide a background in ordinary photography. Because the light from this band is polarized, we can diminish the brightness of this part of the sky considerably with a Pola-screen at the lens. The indicator handle of the Pola-screen provides a simple means of setting the Pola-screen for maximum effect. When this indicator handle points directly at the sun, that is, when its shadow falls along itself, the darkest sky is obtained. No effect is obtained when the camera points close to the sun or directly away from it. Pola-screen control, of course, applies to a clear blue sky, as the Pola-screen has no more effect on sky completely obscured by clouds than does a color filter.

The question arises, how does this method of darkening the sky compare with the use of yellow or red filters? Granting that the picture to be taken is in such direction with relation to the sun that the Pola-screen applies, the use of the Pola-screen has two advantages. The sky only is affected, since the light coming from the foreground object is not polarized. Therefore the monochrome rendering of the foreground object is not affected, as shown in the photograph of the yellow brick building in plate 5. This rendering can be very seriously affected by the use of yellow or red filters. Yellow or red brick buildings, faces, and other objects reddish in color, photograph unnaturally light; blue objects photograph unnaturally dark when deep yellow or red filters are used. The second advantage in favor of the Pola-screen is that the effect is variable. By merely rotating the Pola-screen at the lens, any effect in the sky, from very light to very dark, may be obtained.

The Pola-screen may be used with a color filter. If we are willing to sacrifice some color rendering, we can obtain sky effects similar to those in infrared photographs, on ordinary panchromatic materials by using the Pola-screen with a red filter. In some respects, such photographs are preferable because the trees and grass are not rendered extremely light as in the case of infrared photographs.

Pola-screen offers the only known way of obtaining dark sky effects in color photography.

Perhaps the most beautiful results with the Pola-screen are obtained with the dark blue sky as background when objects are photographed in natural color. When we look at objects, such as blossoms, trees, buildings, etc., against the sky, ordinarily we cannot fully appreciate their colors because the sky is very much brighter, and our eyes tend to seek the lighter parts of the scene. When, however, the sky is darkened, many things assume a new and strange beauty. Many subjects are rendered actually lighter than the sky background, so that our attention is no longer diverted from the subject but is drawn to it for a full appreciation of its color and form. The Pola-screen type IA rather than the type I is recommended for color photography.

So far we have discussed what can be done with the Pola-screen over the lens alone. For these applications the exposure increase is about four times for the type I Pola-screen, and about two times for the type I A. These factors apply irrespective of the angular position of the Pola-screen. When used with a yellow or red filter, the type I Pola-screen factor will be between two and four, which should be multiplied by the factor of the filter.

POLA-SCREENS OVER LENS AND LIGHTS

We shall now turn to effects obtainable with a Pola-screen at the lens and large Pola-screens at the lights. To understand these effects, let us consider for a moment the nature of the light reflected by most common objects. The light reflected from most surfaces consists of two parts which are technically known as the specular and diffuse components. The specular component forms what we know as gloss and enables us to see more or less distinctly an image of the source of light. Light reflected from polished metallic articles is almost entirely specular, whereas that reflected from chalk is almost entirely diffuse. The diffuse component is reflected without gloss in all directions.

Now, if the ray of light which is illuminating the subject is polarized, the reflected rays which form the specular component are still polarized, but the rays reflected diffusely are not, as shown in figure 4. If we look at the subject through a Pola-screen, we can turn the screen so that practically all of the specular reflection is stopped, and see the subject by diffusely reflected light. This fact, which is extremely important, permits many applications. The use of Pola-screens in front of the lights, illuminates the subject with polarized light. Another such device at the camera lens permits photographing by diffusely reflected light alone. This is desirable in many cases, because the specularly reflected light obscures more or less the detail which it is desired to record. If the Pola-screen at the camera is rotated, some of the specular light is allowed through, so that the amount of reflections permitted is under the control of the photographer. When the camera Pola-screen is rotated so that its vibration plane is actually parallel to that of the specular ray, the ray is transmitted even more freely than is the diffuse ray, so that the subject appears to have even brighter reflections and more glass than it actually does have. The most important point about reflection control with Pola-screens at both lens and lights is the freedom in photographing-angle. The use of a Pola-screen at the lens alone restricts the reflection control to surfaces oblique to the camera axis, but the technique just described imposes no such restriction.

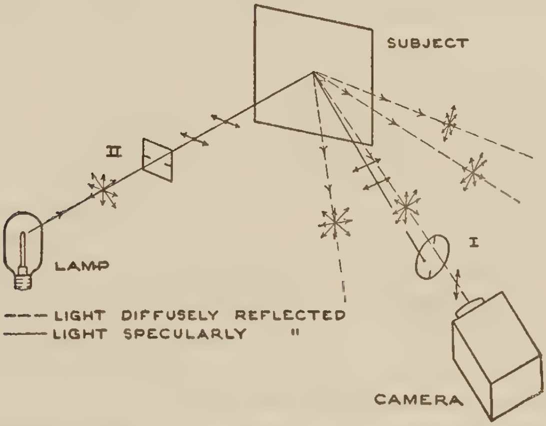


FIGURE 4.—Photography by diffusely reflected light, using Eastman Pola-screens. Light reflected specularly retains its polarized form; it may therefore be cut out by a Pola-screen at the camera. I indicates a Pola-screen, type I; II indicates a large Pola-screen, type II. The indexes on the two Pola-screens show their planes of vibration.

Possibly the most valuable application of this technique is in copying photographs and other subjects whose surfaces up to now have been considered unsuitable for photographing. Much of the light reflected from the blacks of a matte or rough-surfaced photograph, for instance, is specularly reflected, and, therefore, can be cut down by the Pola-screen technique, resulting in a much deeper black, as shown in plate 6. Such photographs, when viewed or copied by polarized light, are startling in their changes. The surface texture, which is usually troublesome in the rough-surfaced print, practically disappears. There is also a great improvement in the rendering of shadow detail.

Oil paintings, ordinarily very difficult to photograph, become very simple indeed. The reflections from the canvas texture, from varnish, from age cracks, and from the pigments themselves disappear, so that the picture is not obscured by rows of bright spots. We can now record the painting instead of its surface.

The effect of this control on polished carved wood is remarkable. If we go to the extreme, the grain is brought out in a remarkably clear manner, and the gloss practically eliminated. Optically, we can remove the varnish. If we go to the other extreme, that is, setting the lens Pola-screen parallel to those at the lights, the polish is enhanced, and the grain subdued. The control in this direction is less than that possible in subduing the reflections.

If it is desired, the reflections from transparent wrappings may be greatly subdued. The effect on lacquer is quite remarkable. Glossy lacquer may be made to appear matte or its glossiness may be apparently increased.

Pola-screens should be particularly valuable to those engaged in clinical photography. The reflections from wet surfaces of clinical specimens frequently hide detail which it is desired to record. These reflections may be subdued to any desired extent to show up detail. One of the effects of removing surface reflections is to show up very strongly small differences in skin color. Slight skin discolorations, incipient rashes, and so on, may be shown very well.

We believe that there are a number of unexplored fields for the Pola-screen, for instance, in unusual lightings and unusual background effects. As one example—if we place a light directly in front of the camera, the lens flare normally resulting degrades the contrast of the picture. If Pola-screens are placed at the light and the lens, the brightness of the light itself may be very greatly subdued with very little effect on the illumination of the subject.

A background of variable brightness is provided by the use of an aluminized sheet (such as a cine or Kodascope screen), lighted by a spotlight through a type II Pola-screen. The sheet is placed to throw a bright reflection into the lens. Rotating a type I Pola-screen at the lens varies the background brightness from very dark to very bright.

Another effect of possible interest in motion picture title work involves cellulose sheeting and transparent cellulose tape. When placed between crossed Pola-screens, the sheeting can be made to appear either light or dark, depending upon its angular position. Various colors result from the use of varying thicknesses, so that patterns in vivid color can be formed by multiple layers of the cellulose material.

TECHNICAL DETAILS

The most suitable negative materials for use with Pola-screens are the panchromatic materials now in general use. Although it is possible to use orthochromatic or even noncolor-sensitized materials, the exposure increase is greater.

The Pola-screen for lens use must be screened from all extraneous light by the proper lens hood.

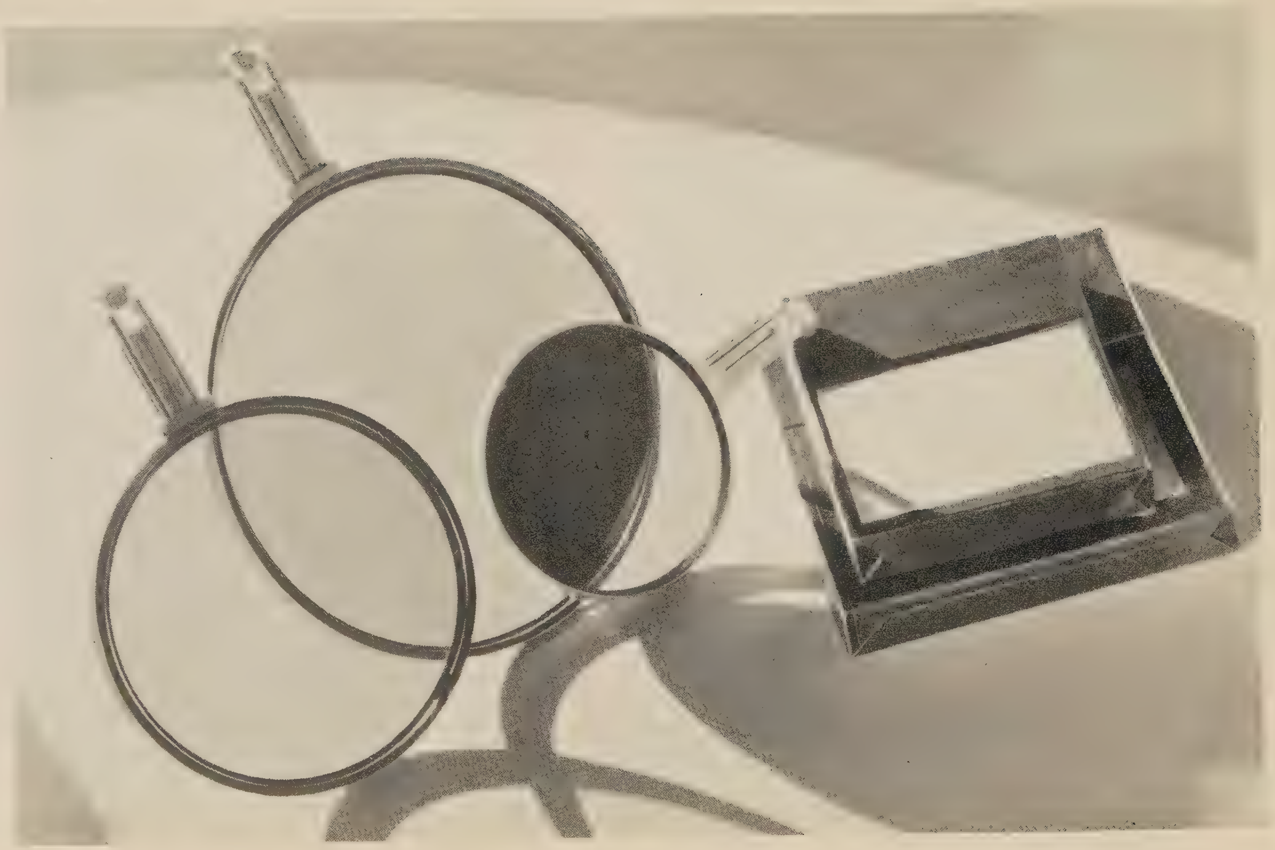
The screens supplied for light source use are not suitable optically for use over a lens. Neither can the Pola-screen for lens use be applied to lights.

WHAT CAN BE DONE WITH EASTMAN POLA-SCREENS

A. Pola-screen (type I or I A) at the lens only. Exposure increase required, four times.
  1. Photographing obliquely through glass or water.
  2. Subduing oblique reflections which hide surface detail.
  3. Subduing bright oblique reflections which interfere with good composition. This oblique reflection control does not apply to metallic surfaces, unless Pola-screens are used over both lens and lights.
  4. Darkening a blue sky when photographing at right angles to the sun. The monochrome rendering of the subject photographed is not affected.
  5. The Pola-screen type I A can be used to darken a blue sky when photographing in natural color, as with Kodachrome.

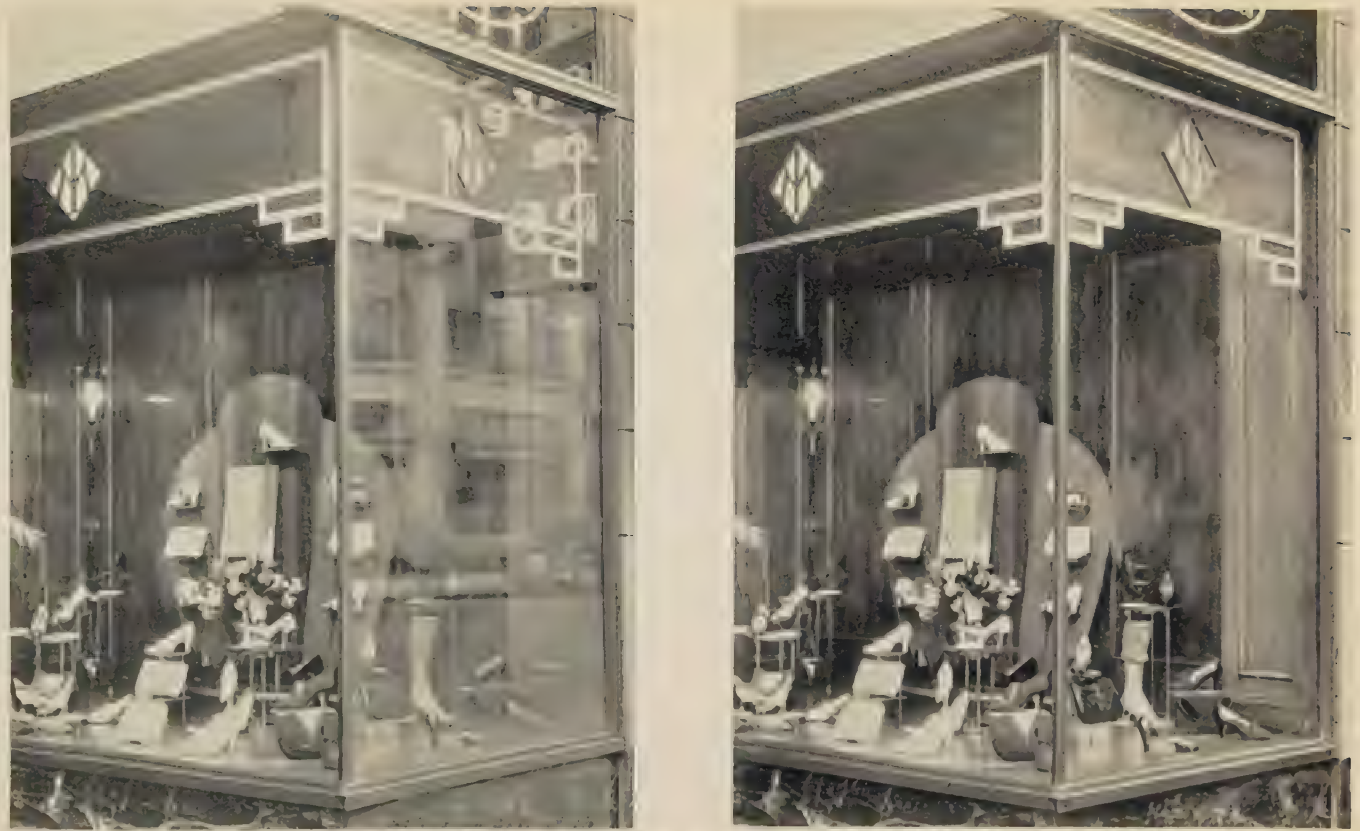
B. Pola-screens (types I and II) at both lens and lights. Exposure increase required, 16 times and up.
  1. Copying rough prints, matte prints, damaged prints, and oil paintings which show strong reflections due to cracks, canvas texture, or brush marks.
  2. Copying any subject with the lights undiffused and quite close to the camera.
  3. Subduing the reflections in many studio subjects, whether or not these reflections are oblique.
  4. Creating unusual lighting and background effects.

The novelty of this subject makes it difficult to say just what application will be most valuable. It is, however, a new tool, by which new effects may be achieved, and its limits are imposed only by the imagination of the user. It is opening our eyes and our cameras to some of the unseen beauties of nature.



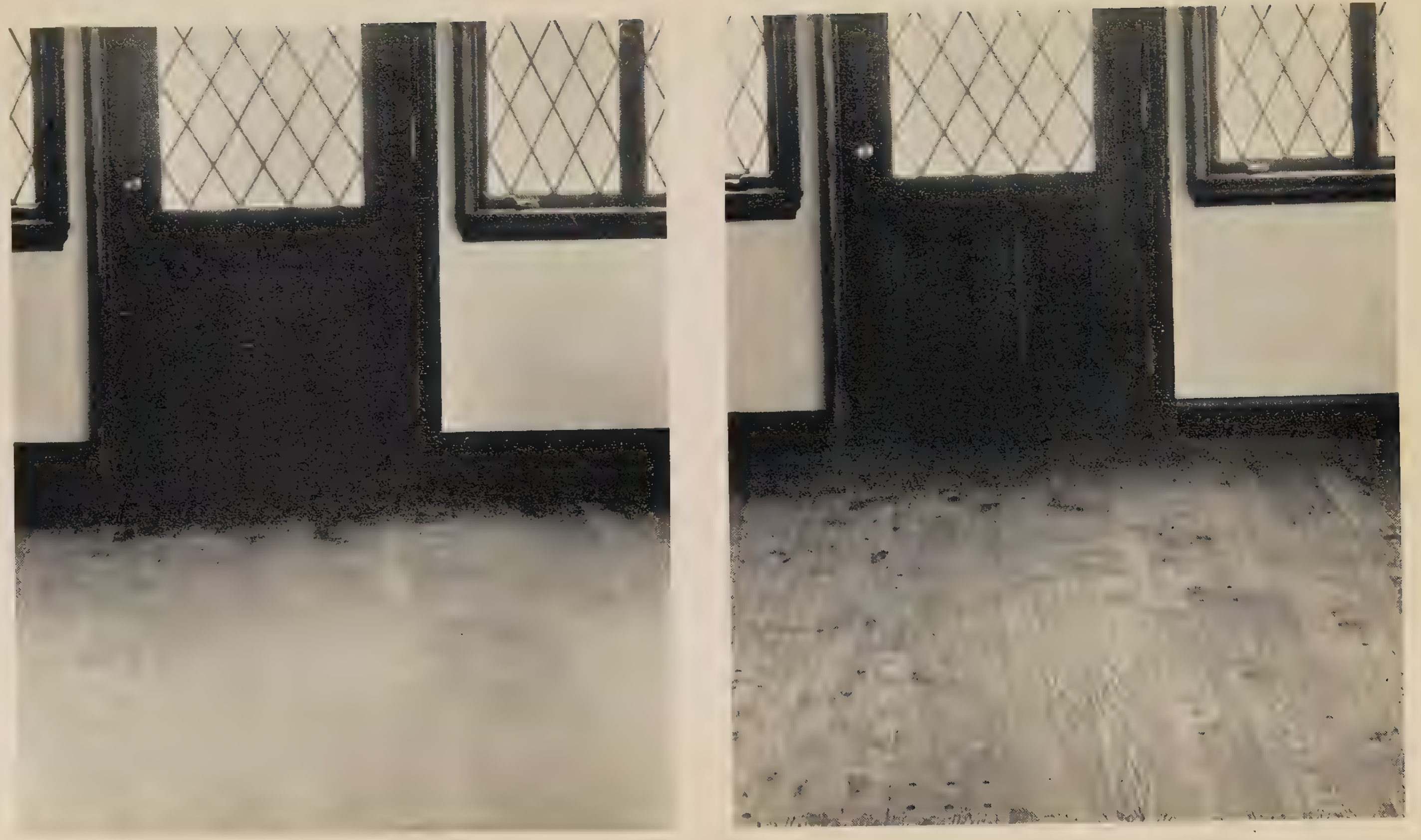
TYPE I POLA-SCREENS IN COMMERCIAL SIZES: 2½″, 3½″, 4½″.

The largest Pola-screen is passing polarized light; the two others show the extremes of control of such light according to their angular position.



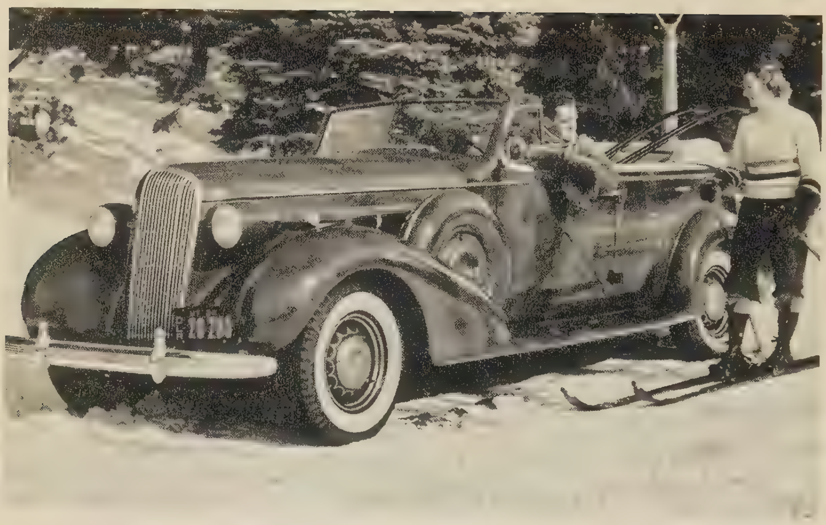
THIS WINDOW, IN WHICH BOTH PANES WERE OBLIQUE TO THE CAMERA AXIS, WAS PHOTOGRAPHED IN DAYLIGHT.

The picture on the left was made without a Pola-screen. Note the reflections. The picture on the right was made with a Pola-screen over the lens alone, without change in lighting conditions. Note that the reflections from the windows are subdued. If the camera angle is well chosen the reflections are practically eliminated. The Pola-screen is not effective in photographing a window straight on.

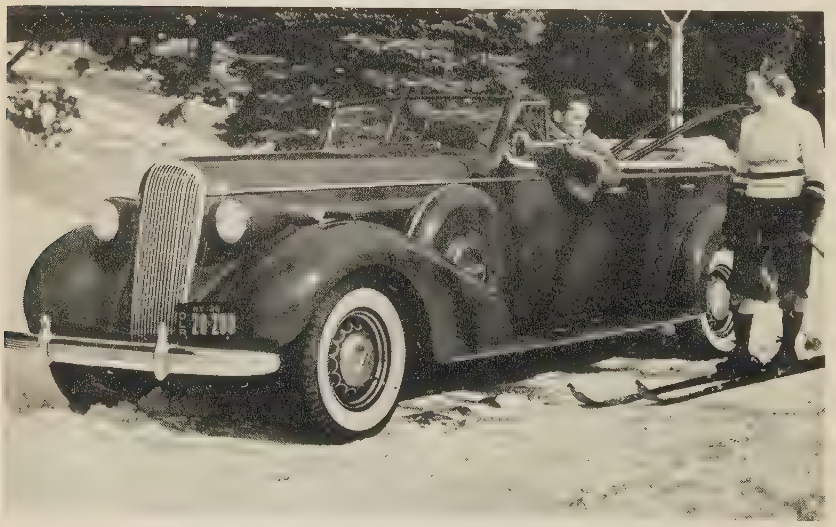


PHOTOGRAPH OF POLISHED OAK-PLANK FLOORING, TAKEN TOWARD THE LIGHT.

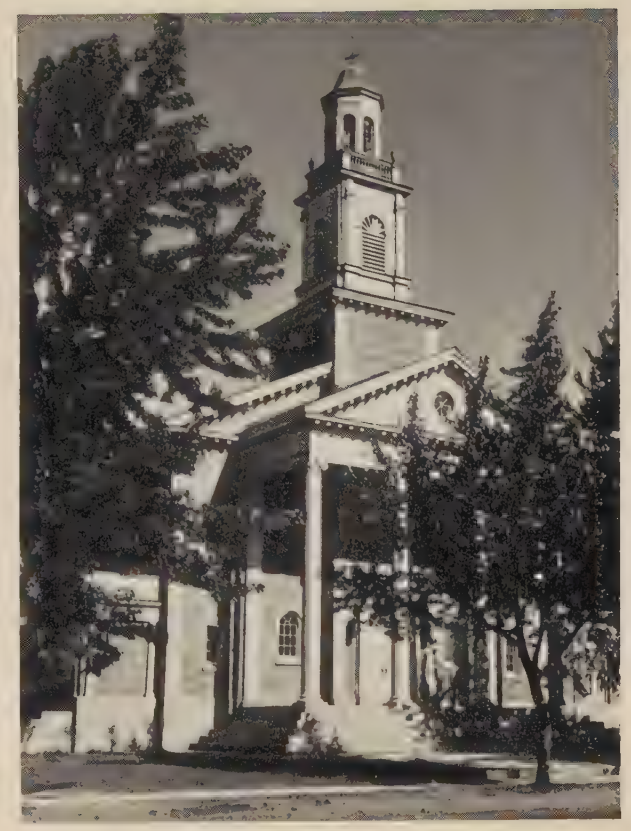
The picture on the left was made without a Pola-screen, and shows reflection ordinarily encountered. The picture on the right was made with a Pola-screen over the lens alone. Note that the reflection from the door and windows is reduced to show grain and constructional details in the flooring.



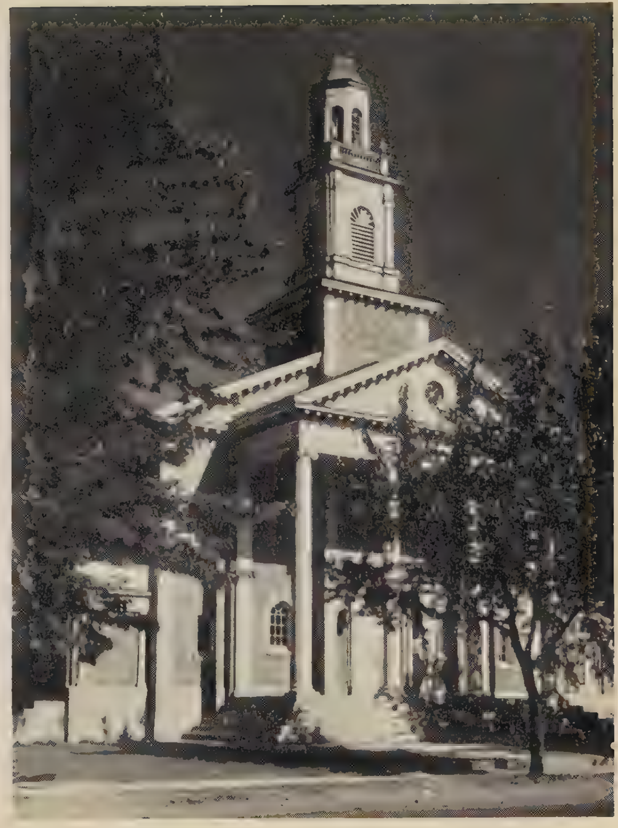
1. NO POLA-SCREEN. NOTE OBJECTIONABLE REFLECTIONS ON SIDE OF CAR.



2. POLA-SCREEN OVER LENS ALONE. THE OBLIQUE REFLECTIONS ARE SUBDUED.

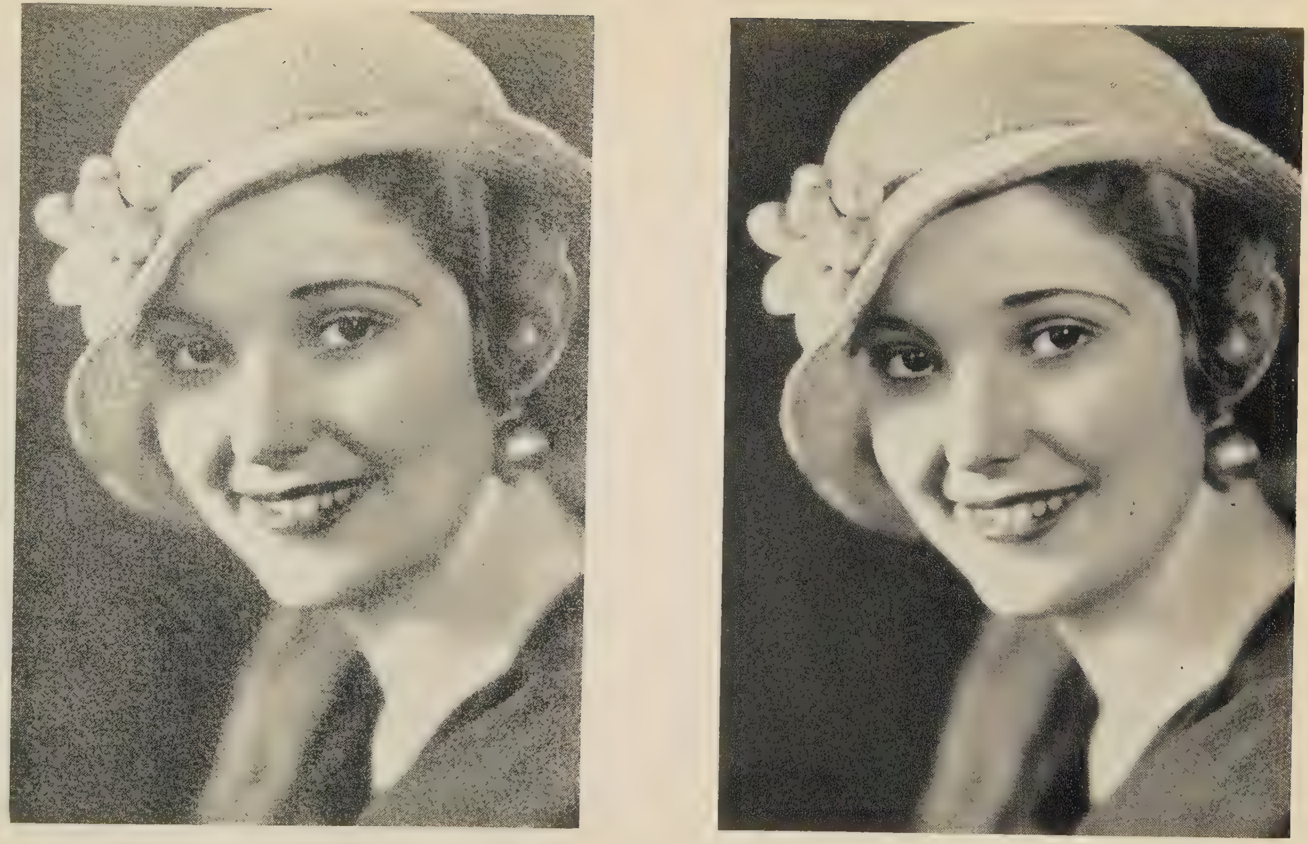


1. NO POLA-SCREEN, NO FILTER.



2. POLA-SCREEN SET FOR DARKEST SKY.

The Pola-screen acts as a variable depth filter for dark sky effects and does not affect the monochrome rendering of other objects. With Pola-screen set for darkest sky (indicator handle pointing toward the sun) as in the picture on the right, above, note that the rendering of the yellow brick is unaffected



1. NO POLA-SCREEN.

2. POLA-SCREEN OVER LIGHTS AND LENS.

Reproductions of a rough-surface photograph. The picture on the left was taken with the best possible lighting, no Pola-screens. The one on the right was taken with Pola-screens over lights and lens, crossed. No diffusers used. With Pola-screens over lights and lens, the illuminating angle does not matter. The lights may be placed so close to the camera that ordinary photography would be hopeless.

MEASURING GEOLOGIC TIME: ITS DIFFICULTIES

By Alfred C. Lane

[With 2 plates]

In measuring anything, three things are necessary: First, a definite starting point; second a unit of measurement; and third, a method of counting those units. All processes may also be divided into three kinds, which we have in the geologic story and which are variously useful in measuring: The periodic, the progressive, and the paroxysmal.

The periodic processes are not merely those that depend upon the days and the yearly seasons, but also longer cycles, such as the 23-year double sunspot cycle, and the 25,000-year precessional cycle. Others mentioned by Clough have been diligently sought. The only one of these of which there appears to be as yet indisputable geologic evidence is the double sunspot cycle, which Abbot [1] and Bradley [2] have studied. To this matter we will return later.

The progressive processes are the one-way activities, such as cooling and the lowering of continents by rivers, which "draw down eonian hills and sow the dust of continents to be."

Finally, we have the paroxysmal processes, illustrated by the earthquake and the volcano. Whenever we have a progressive accumulation of strain which relieves itself when a particular amount is reached, we may have a periodic recurrence of paroxysms. The classic illustration of this is the Old Faithful Geyser with its 65-minute period.

THE STARTING POINT

The starting point of measurement, corresponding to an engineering datum plane, should be unique and not easily mistaken or confused with some other point. It should also be at least as precise as the unit, preferably more so. A cyclical process does not in itself give a good starting point, since conditions are repeated over and over again. A year must be labeled by reference to some unique event, such as the Declaration of Independence of the United States. Not only the birth of a nation, but the birth of an individual is also a unique event, and it is natural in writing the biography of an individual to start with his birth, which is a paroxysmal and unique event. However, some other event—his accession to the throne, Mahomet's flight (the Hegira), or his death—may also be unique, precise, and better known. The chronology according to the birth of Christ, unique as that event was, was introduced long after his life, and his actual birth was probably not the real starting point.

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[1] Abbot, C. G., Solar radiation and weather studies. Smithsonian Misc. Coll., vol. 94, No. 10, pp. 71-75, 1935.

[2] Bradley, W. H., Nonglacial varves with selected bibliography. Exhibit (2) in Report of the National Research Council Committee on the measurement of geologic time. May 1, 1937.

The same difficulty comes up if one wishes to measure geologic time from the "birth time of the world," which is the title of a book by J. Joly. We know too little about it, and, in fact, it is hard to define what we mean by it. It is therefore not the place to begin our reckoning.

The same thing applies to other points in the geologic story. The farther back we go the more difficult it will be to get a general agreement as to what should be the starting point, how precise it is, and what it means. To be sure, there are showers of volcanic ash (bentonite) which must mark a rather precise epoch, but they are hard to recognize and are more or less local. While they may well be used for dating some small bit of geologic time, they can hardly be a generally used starting point.

It is a trite saying in geology that the present is the key to the past. The present is unique. It is also best and most precisely known. It should be, therefore, and is, the starting point for any general estimates of geologic time. From it and from what has happened within the history of man we work backward. The one difficulty about the present is that it is changing, but for most of our geologic time calculations it makes very little difference what historic date we use as a datum, since few of the methods of measuring geologic time can pretend to an accuracy of 1 percent, and most of them deal in units of thousands or millions of years.

It may well be, however, that A. D. 1920 will, to the geologist a million years hence, be marked to within 10 years by the abundant relics of discarded internal combustion engines, the relics of the great war close below, a line of fossils indicating a cosmopolitan flora and fauna, and the widespread burning of coal, of which, to be sure, there would be signs in the previous 100 years.

Our physical laws and scientific results tell us how two states are connected, but in many cases it is a matter of indifference with which we start; one or the other must be arbitrarily given. The present, then, is our starting point, and the baseline of our estimates is the record of human observations, whether it be those recently described so graphically by Ludwig in his book, The Nile, [3] such as the lowering of the Nile bed 25 feet in 3,000 years, and, near its mouth, the earth end raised 52 inches in 1,000 years; or those poetically described by Alfred Noyes in his Watchers of the Sky:

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[3] Ludwig, Emil, The Nile, pp. 26, 328–329. Viking Press, 1937.

* * * The records grow
Unceasingly, and each new grain of truth
Is packed, like radium, with whole worlds of light.
The eclipses timed in Babylon help us now
To clock that gradual quickening of the moon
Ten seconds in a century. Who that wrote
On those clay tablets could foresee his gift
To future ages? * * *

THE UNIT OF MEASUREMENT

The unit must be identifiable in the geologic record, and must be of uniform length. Of all the units of which one might think, the year is preeminent. The periodic processes are obviously those which will best give us the unit. The second and the day are obviously too short, and, moreover, as yet no daily variations have been recognized in the geologic record, whereas the changes of the seasons have left indelible records. These have been recognized not merely in tree rings, present and fossil, in the growth lines of fish scales and stalactites, the bands of anhydrite in the salt beds which show evaporation under changing conditions of temperature, but also in a wide range of deposits.

To such bands the Swedish term "varves" is applied, since in Sweden they have been worked by G. de Geer into a systematic chronology of post-glacial time. The greater melting of the ice in summer is marked by coarser clays. Finer deposits settled in the lakes on the margins of the glaciers during the winter. Baron de Geer's work has been continued and extended by his pupil, E. A. Antevs,[4] and by Chester A. Reeds and others. But beside these distinctly glacial varves or bands there are also bands of more and less organic matter which are almost surely seasonal, especially when layers with traces of ephemerids (mayflies) or pollen distinctly mark the seasons, as De Geer found. Some of the more important papers are cited by Bradley,[5] from whom we take plate 1.

One difficulty at once arises: How do we know that some of these bands do not represent the two seasons a year that characterize certain regions? To this there is a two-fold reply. First, such regions are exceptional and are not likely to occur in regions of glaciers and of temperate flora; second, studies such as those of C. G. Abbot [6] seem to show the double sunspot cycle of years (fig. 1). Further study

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[4] Antevs, E. A., The last glaciation. Amer. Geogr. Soc., Research Ser. No. 17, 1928. See also bibliography in Rating the geologic clock, Rep. 16th Int. Geol. Congr., Washington, pp. 145-167, 1936.

[5] Loc. cit., and esp. U. S. Geol. Surv. Prof. Paper 158-E.

[6] Loc. cit., footnote 1.

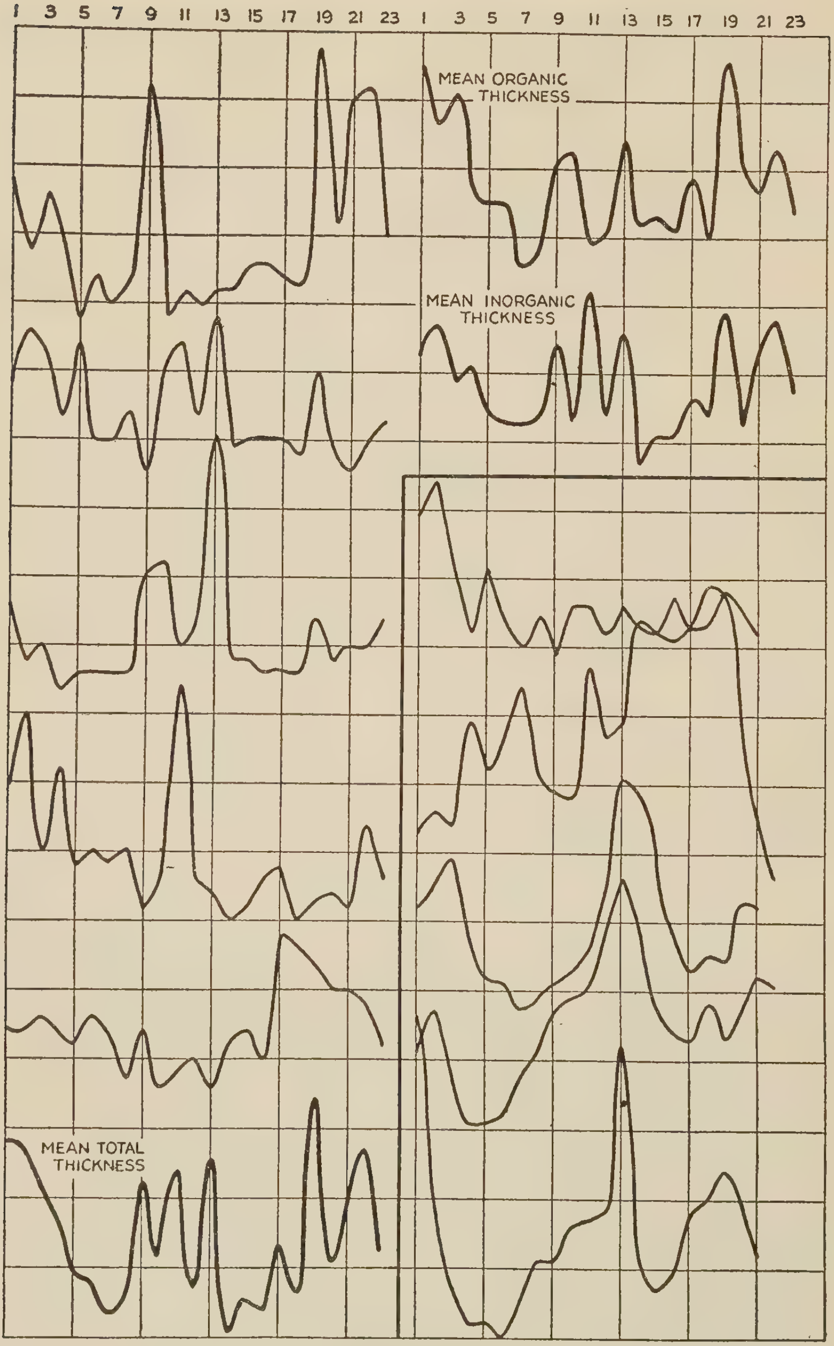

Figure 1.—Curves showing the 23-year cycle in thickness of Pleistocene and Eocene varves. (C. G. Abbot, Solar radiation and weather studies, Smithsonian Misc. Coll., vol. 94, No. 10, fig. 32, 1935.)

should be made of all these banded deposits to see if this or other identifiable cycles can be determined.

Another question is whether we can assume that the year has been of the same length. In an expanding universe, unless the gravitation constant also changes to match, the year would have been shorter when the earth was nearer the sun.

While one might also think of the addition to the weight of the earth by meteorites and their effect upon its orbit, there is such a lack of meteoritic material in the rocks accessible to the geologist that any such effect during the time they were laid down would be an infinitesimal of the second order. The same description would apply to the effect of the loss of mass by radiation from the sun.

But the year is a rather short unit for the longer geologic times. Is there any practical longer unit? A number of longer periods have been suggested by E. Huntington, Clough, and others,[7] but only three have been seriously applied. One is the precessional period of 21,000 to 25,000 years. In half the period the North Pole changes from being inclined toward the sun when the earth is farthest from the sun in her elliptical orbit around it, to being inclined toward the sun when the earth is nearest it, thus making the two reasons for summer heat reinforce each other in the Northern Hemisphere. Moreover, since the earth moves faster the nearer it is to the sun, there will be extra hot and short summers in the Northern Hemisphere from the spring equinox to the fall. The difference is at present only 3 days, but when the orbit of the earth is more elliptic it may be as much as 30 days.

As the two hemispheres are unequally balanced in proportions of land and water, the northern having much more land, it seems quite possible that this cycle should register itself in climatic changes. Bradley's bibliography (see footnote 2) cites papers by himself, Gilbert, Korn, Stamp, and Wolansky, which discuss supposed signs of such cycles in rhythmic alternations of strata. Oil geologists are making further studies. Such cycles should be alternately more and less conspicuous, depending upon a longer rhythm—that in which the ellipticity of the earth's orbit varies. However, the effect upon climate is indirect and depends upon geographic arrangements of land and water which may vary quite independently. The whole of human history recorded in accurate measurements has only covered a quarter of a cycle. The geologist who a hundred thousand years hence has four or five such cycles to look back upon will be better able to judge their worth as time units.

The longer cycle of varying ellipticity of the earth's orbit has even greater disadvantages. We have passed through so little of it that we know little of its geologic effect, and, moreover, it is a complex cycle built up from the cycles of the motions of the various planets, which also affect the sun and, through the sunspot cycle, the earth.

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[7] Lane, A. C., bibliography in Rating the geologic clock, Rep. 16th Int. Geol. Congr., Washington, pp. 158–167, 1936.

Thus all these cycles are as yet unsuitable either as units, or, we may add, to be counted in estimating geologic time. We say "as yet," for the cyclothems of R. C. Moore [8] in the coal measures, the rhythmic bandings of flint in the chalk of the Norman coast, and similar rhythms in many other places suggest possibilities.

There is still another class of cycles deserving a word in this place, since they are highly important in geology, even though not suited for time units. It has been suggested that there is a steady and progressive accumulation of strain in the crust of the earth, to which it yields, perhaps spasmodically, or perhaps periodically. One might consider these as unit cycles. As we have already remarked, this is quite conceivable. Not only the discharge of many geysers, but the action of the violin bow and of the water clock is of this nature. But when we examine a little more closely we see that at present, at least, if we take the table given by Stille, figure 2 (after Bull. Amer. Assoc. Petroleum Geol., vol. 20, p. 852, July 1936), such cycles cannot be of use in measuring geologic time. The recognition of such cycles, and the proof of their regularity, if such there be, is rather a goal of geologic investigation.

There are two causes of the accumulating strain which have been cited. The one is the shrinkage of the interior due to the loss of energy, especially as heat, causing the crust to tend to collapse when the strain thus produced surpasses its strength. This idea of the crust wrinkling like an old apple has been accepted by a line of writers of distinction, the present champion being Prof. H. Stille,[9] of Göttingen. That there has been a cycle of sedimentation corresponding to each great geologic period is widely accepted and goes back at least to Newberry. The concept has been most systematically worked out by Schuchert,[10] who also believes that the periods are separated by epochs of wide crustal disturbance. That these are relatively short and sharp is also widely held, as has been recently emphasized by R. T. Chamberlin.[11] But this is not universally accepted, and the idea has been vigorously opposed by E. W. Berry.[12]

In view of the facts that the volcanoes of Italy and Iceland and other regions have been pretty continuously active since some time in the Tertiary, which we shall find reason to believe was millions of years ago, and that mountains like the Coast Range of California

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[8] Studies on the Carboniferous of the midcontinent region, Bull. Amer. Assoc. Petroleum Geol., vol. 13, p. 191, 1929.

[9] Bull. Amer. Assoc. Petroleum Geol., vol. 20, pp. 849–880, 1936.

[10] Nat. Res. Counc. Bulls. 80 and 85. See also Bull. Geol. Soc. Amer., vol. 32, pp. 147–150, 1921.

[11] Certain aspects of geological classifications and correlations. Science, vol. 81, p. 184, 1935.

[12] Shall we return to cataclysmic geology? Amer. Journ. Sci., ser. 5, vol. 17, pp. 1–12, January 1929.

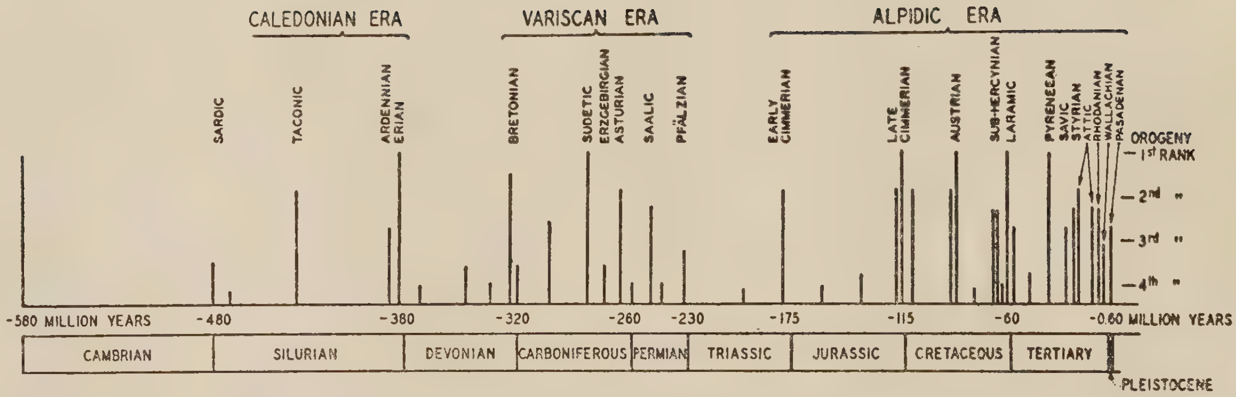

FIGURE 2.—Dates, by abscissas, and importance, by ordinates, of the mountain-building (orogenic) upheavals of the past. (After Stille.)

are also still growing and have been since the Tertiary, it is clear that division by epochs of mountain building or the volcanic action associated therewith cannot be precise.

Nor is there such agreement among authors as to the strength, number, and regularity of these epochs of mountain building (last and best presented by R. C. Moore, C. Schuchert, and H. Stille) as to make them available for geologic time measurement. Figure 2 is after H. Stille.[13]

Another cause of accumulating strain, to be regularly relieved, is of exactly the opposite nature. It was suggested by J. Joly that if the earth contained anything like the amount of radioactive material that the rocks of the surface seem to, from its decay the earth would be generating more heat than is discharged through the crust; that thus heat would accumulate and the crust be melted from below until it gave way and discharged the heat in lavas, etc. This idea has been elaborately worked out by A. Holmes and H. Jeffreys, and also discussed by Urry.[14]

It is clear that these explanations of cycles are inconsistent and of uncertain application. Moreover, we know far too little of what the real normal geothermal gradient is under the land. The old assumed rate of 1° F. for every 60 feet or so of depth proves much too rapid for large areas in Canada and South Africa.[15] Finally, we know nothing of the rate of loss under the ocean which covers three-fourths of the surface. Thus both the rate of loss and the content of radioactive elements as computed by Urry with the best available data are hazardous extrapolations, though there are reasons for believing that Urry's curve is not far off. The meteorites are but very slightly radioactive, and the basaltic rocks less radioactive than the granitic, and the weight of the earth has made the belief general that the interior is in composition more like a meteorite. Robley D. Evans suggests that early data as to the surface rocks are questionable.

It is safe to say, therefore, that such cycles cannot serve as units of geologic measurement, that the curve of rhythms and revolutions with regular cycles such as Holmes gives is as yet an ideal,[16] and that what Kirsch says [17] is wise warning.

> The theory of magmatic cycles permits one to draw a number of more or less necessary consequences which may be compared with the facts of experience. It is to be hoped that in the coming years its fruitfulness in guiding geologic and

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[13] Loc. cit. See also F. Nölkein, Scientia, vol. 1, No. 1, pp.19–30, 1933; and F. P. Shepard, Sealevel and climatic changes relating to late Paleozoic cycles. Bull. Geol. Soc. Amer., vol. 47, pp. 1197–1206, 1936.

[14] Holmes, A., Thermal history of the earth. Journ. Washington Acad. Sci., vol. 25, pp. 169–175, 1935.
Jeffreys, H., The earth, ch. 8, The thermal history of the earth, 2d ed. Macmillan, 1929.
Urry, W. D., The occurrence of radium, uranium, and potassium in the earth. Proc. Amer. Acad. Arts and Sci., vol. 68, No. 4, pp. 137–144, Mar. 1933.

[15] Koenigsberger, J. G., Beitr. Zeitschr. Angew. Geophys., vol. 7, No. 1, pp. 68–83, 1937

[16] Holmes, A., Age of the earth. Benn, London, 1927.

[17] Kirsch, G., Geologie und Radioaktivität, p. 128. Springer, 1928.

geophysical research will be shown, although for the present the possibilities of stretching it to fit various ideas are so great that it runs the danger of being treated with mistrust on the physical side, as an india rubber theory.

In any case, cycles are always spoken of as millions of years long—so long that we have no historic knowledge of more than a small fraction of a cycle. They are not adapted for units of measurement.

The precessional cycle belongs to the solar system, as does the sunspot cycle, and there are numerous other planetary cycles. Any cycles of astronomic origin of greater sweep than the solar system are much longer and would appear in the life of the earth possibly as progressive factors or cycles as long as any we have mentioned. Such would be the great orbit which the whole solar system is describing sidewise around the center of the Galaxy, some 3,000 light years (5.84×10^{12} miles) away at a velocity of about 300 kilometers (183 miles) a second, a cycle of some 20 million years. Such cycles are obviously not suitable as time units. We must then fall back on the year as the unit.

PROGRESSIVE PROCESSES

Leaving, then, the periodic processes and rhythmic cycles for the moment, and accepting the year as a unit even though our accuracy may be only expressed in millions of years, or "decamyriads" of Vernodsky, we pass to those progressive processes, the type of which is the hour glass, by which we measure time.

These are "one-way streets." Among them are the processes of degradation or lowering of the land, whether by wind or water or ice, by the streams lowering the area of their basins or cutting back as in waterfalls or cutting down, the erosion by glaciers, and along the shores of the ocean. Of these activities, a host have been studied, such as the retreat of Niagara Falls and of the Falls of St. Anthony at Minneapolis, the retreat of the cliffs of the Weald on which Darwin made estimates, the recession of the English shores, and the shore from Chicago to Milwaukee. Along Lake Huron, Gordon and I once found a road and plow marks running off the bluff. The road came in again half a mile farther on, and by comparing with old maps, Gordon was able to compute the rate of retreat as 5.7 feet a year.

But what is eroded in one place must be deposited elsewhere, and to match degradation there must be deposition. In all such calculations there is a fundamental "rule of three." So much has been done in a given, historically known time, and so much has been done in all. At the same rate this would have taken a proportionately longer time.

In some cases we may be reasonably sure that the rate of change is not the same. Many activities are asymptotic. They grow less and less as time goes on, if no other factor interferes. For this we sometimes can allow. If, for instance, a continent has an average elevation of 2,000 feet and is being lowered at the rate of 1,000 feet in a million years, then, if the elevation plotted relative to the time may be represented by a hyperbola, the greater the time the slower the lowering and, instead of being absolutely flat in 2 million years, it will be reduced to half the height, and to one-tenth of the height in 10 less 1; that is, 9 times 2 million years. This is the process known as peneplanation.

We have said that there was deposition to match the degradation. In general, the finer the sediments, the less the rate of deposition. Here the cyclic annual varves may help us to estimate the yearly rate of deposition. In the fine-grained sediments it is usually estimated, according to the authors cited by Bradley, as something like 0.1 millimeter, or 250 years to the inch, 3,000 to the foot. In recent deepest sea soundings a rate of deposition of 20,000 to 25,000 years to the foot has been suggested. The coarser the sediments, in general the more rapid is their accumulation. Comparison of the thickness of different rocks in different places formed during the same period gives us some idea of the relative rate of accumulation.

Very elaborate calculations of deposition and denudation have been made, as summarized by C. Schuchert [18] and H. P. Woodward. Such estimates of time are, however, subject to large possible errors, since it is nearly impossible to find exposures or sections of strata where deposition has not been interrupted. If, during the interruption, the lower strata were tilted or converted into land and deeply eroded, such interruptions may be more easily noted, but the gaps (known as diastems), if due simply to underwater currents, may be almost unrecognizable. It is, however, fair to say that at least 300,000 to 400,000 feet of rather fine-grained beds containing characteristic fossils are known, which might easily indicate a time of several hundred million years. If that proved to be not enough, unrecognized diastems could be assumed. On the other hand, it would not be impossible to knock a cipher or two from the age if other methods of estimating time pointed to such action.

When estimates of the composition of the average sedimentary rock are compared with that of the average igneous rocks from which they are supposed to be derived, it is found that there is a shortage of sodium, even making allowance for all the salt beds known or reasonably suspected. It is natural to compare the ocean with a great salt lake, and, noting that all such lakes with no outlet become salt, to suppose that that has also been the case with the ocean. Then, if we can compute the amount of sodium added each year by the rivers, and make allowance for the salt of the salt breezes, for the cyclic sodium derived from the erosion of salt beds and beds containing salt water, the sodium absorbed by sediments in base exchange, and for the rest of the factors tending to increase his estimates of time and those tending to diminish them which Joly listed, we can estimate how long it would take at the present rate to accumulate the salt at present in the ocean. This Joly first did, and his work, first published in the Transactions of the Royal Society of Dublin, has already received attention in the Smithsonian Report.[19] F. W. Clarke has gone over the figures with ampler data.[20]

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[18] Nat. Res. Counc. Bull. 80, pp. 10–64, 1931.

Jones has estimated the time required to make the Lakes Truckee and Winnemucca, shrunken remnants of the large lake known to geologists as Lake Lahontan, as salt as they are in three ways: First, by comparing the increasing saltness given by two analyses 30 years apart; second, by studying the rate of evaporation and the time needed to evaporate the water; and, third, by taking the analyses of the rivers feeding these lakes and computing the time required to bring in the salt.[21]

Of these only the latter method has been used to obtain the age of the ocean, and even in that there are difficulties which prevent our relying upon the figures. In the first place, the analyses of river waters upon which estimates of the yearly contribution of sodium were based do not give enough weight to the composition in time of floods, at which most of the run-off takes place. In the second place, there is no assurance that the present climate and run-off is a fair average of that in past times. In fact, many geologists believe that a period of extra uplift and glaciation, exposing a lot of rock to weathering processes, has occurred in the immediate past, and that the present state of things is not yet back to average. In the third place, if we may trust Schuchert's paleographic maps, the present continents are in general larger than in the past.

All these factors would tend to make the estimate of time of accumulation of oceanic sodium (about 100 million years) too low. On the other hand, any original sodium in the ocean water, from whatever source, would make the estimate too high.

Moreover, if we compare any other element than sodium in river water and the ocean, we get very different results. Some of these elements, such as calcium and magnesium, are promptly seized by organisms to make shells. But chlorine offers a different story, and there is reason to look for a volcanic source for much of the chlorine and to suppose that it was more abundant in the early ocean. Indeed, endeavors have been made [22] to estimate geologic time from the change in the Na:Cl ratio in sea water, but the buried (connate) sea waters have been exposed to change, and the rate of change of the ratio of sodium to chlorine has been irregular.

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[19] Joly, J. Smithsonian Ann. Rep. 1899, pp. 247–288, 1901.

[20] Clarke, F. W. Data of geochemistry. U. S. Geol. Surv. (5 editions), especially chs. 1–5, and pp. 146–151.

[21] Jones, J. C., Geological history of Lake Lahontan. Carnegie Inst. Washington, Publ. 352, pp. 1–50 1925.

[22] Lane, A. C., Geological column; France, Britain, Germany, United States. Lefax, pp. 9–357, October 1919, Philadelphia.

GEOTHERMAL GRADIENT, THE COOLING EARTH

There is another progressive activity which has been used to estimate geologic time which goes back to the great name of Kelvin (Sir William Thomson). This was so much discussed at one time that it should be mentioned here, especially as it has recently been studied by Spicer.[23] This method depended upon the cooling of the earth. Obviously, if the earth is losing energy from the interior, as it actually is, and if we know the rate at which it is escaping—and this Kelvin estimated from the increase of temperature with increasing depth in mines—we can estimate how long it has been escaping, if we know the initial condition.

Unfortunately, Kelvin made assumptions which are not likely to be true. In the first place, he assumed a practically instantaneous drop of the surface temperature at the time of consolidation of the crust to practically the present temperature instead of the critical temperature of water, which might have been the surface temperature if the ocean was then all or mainly in the atmosphere. On the other hand, if there were then no ocean and less temperature, the surface temperature might have been down to 200° lower than at present, and have risen slowly as water and gas emerged from the interior. In the second place, he assumed a uniform temperature at the beginning from surface to center. In the third place, he assumed an increase of temperature of about 1° F. in 60 feet depth in the earth. Later observations in Africa and Canada make it possible that the normal rate of temperature increase is only one-half or one-third as much, and we know nothing of what it is under the ocean—that is, for three-quarters of the globe. Finally, he made no allowance for the then unknown effects of radioactive disintegration which in earlier time would have been even greater than now. The result is that it is not difficult to select possible geothermal data to fit a wide range of ages.[24]

However, the geothermal gradient has also been used to estimate the time since the last ice age. For the wave of heat which started down when the ice retired does not seem to have reached the bottom of the deeper mines and wells. This is shown in such a well as that of figure 3, after C. E. Van Orstrand. The decrease of temperature toward the surface from the lower levels of Michigan mines would indicate a temperature near freezing near the surface. The postglacial wave of heat seems to have reached a depth of only between

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[23] Bull. Geol. Soc. Amer., vol. 48, pp. 75–92, 1937.

[24] Lane, A. C., Schaeberle, Becker and the cooling earth. Science, n. s. vol. 27, pp. 589–592, 1908.

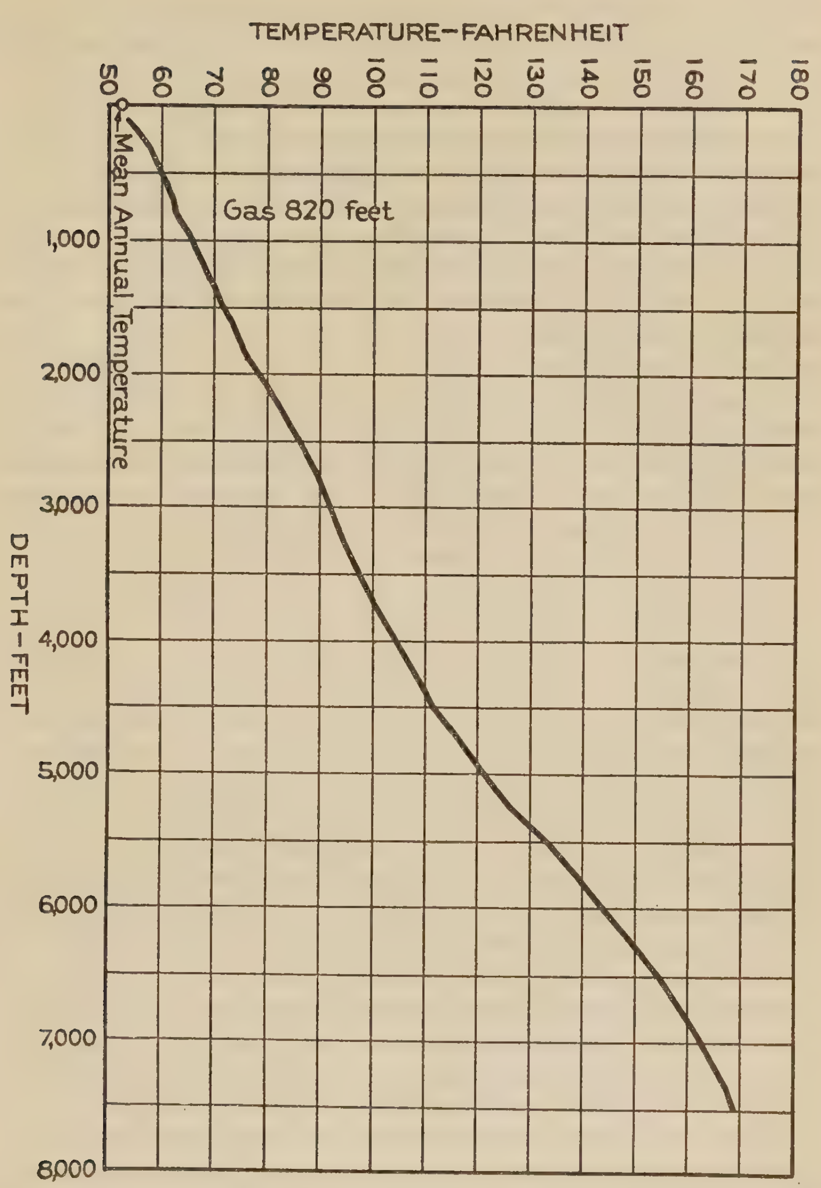

FIGURE 3.—Curve showing the temperatures of the rocks for various depths, increasing, but increasing more rapidly at the bottom, indicating a heat wave which has not reached the bottom. (C. E. Van Orstrand, On the nature of isogeothermal surfaces, Amer. Journ. Sci., vol. 15, p. 514, fig. 8, June 1928.)

3,000 and 5,000 feet.[25] The variation in geothermal gradient as a possible index of oil or gas has been studied by Van Orstrand and workers with K. C. Heald for the American Petroleum Institute.

The difficulties in obtaining age results from temperature gradients are to some extent the same as those inherent in all progressive processes—uncertainty as to initial conditions and as to how far results have been affected by other factors. The change of rate of activity in time is also uncertain, but usually we can know in what direction it is. We also know little, accurately, as to the diffusivity of rocks as they lie in the ground, saturated with water fresh or salt, or dry and containing only oil or gas.

Minor methods of estimating geologic time, the accumulation of meteorite material, of gases in the atmosphere, organic changes, variation in the position of the pole, and others of the 40-odd methods which geologists have tried, which are occasionally useful, may be passed over to come to those which seem the most important and widely useful—"popcorn" methods of measuring geologic time by atomic decay and the accumulation of the products thereof.

GEOLOGIC TIME RECKONED FROM ATOMIC DISINTEGRATIONS

If one watched a popcorn machine and noted the number of kernels popped in a second, and noted how much was popped, one could figure how long it had been running. If, after a few minutes in the dark, one looks at a luminous dial or hands of a watch with a pocket lens, one can generally see that the luminosity is not quiet, but is due to a shower of sparks, each of which represents an exploding atom. While in detail these explode irregularly, yet ordinarily in any radioactive element there are many flashes per second per milligram, and the number per hour is practically constant and characteristic of the element, regardless of any variation of pressure, temperature, or electric charge that is likely to occur naturally in the earth's crust.

The study of these explosions has been the subject of many physical investigations. Three rays are said to be emitted by the explosion, none of them visible but causing luminosity in certain compounds. The alpha ray is really a nucleus of the gas helium, and the residual atom has its atomic weight lowered by 4. The Geiger counter is an electric device for counting them, a method much more accurate than visually counting them in a scintilloscope. A recent counting study is that of Robley D. Evans and G. D. Finney.[26] The counting has been continued by C. Goodman. The physical difficulties and the uncertainties produced by the "background effect" of unwanted particles are still great.

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[25] See Recent geothermal measurements in the Michigan copper district, by James Fisher, L. R. Ingersoll' and Harry Vivian, with discussion by A. C. Lane, P. Weaver, and L. Gilchrist, Trans. Amer. Inst. Min. Met. Eng., vol. 110, Geophysical prospecting, pp. 528-535, 1934, and the papers referred to in Lane's discussion.

[26] Finney, G. D., and Evans, R. D., The radioactivity of solids determined by alpha-ray counting. Phys. Rev., vol. 48, pp. 503-511, Sept. 15, 1935.

The beta ray is an electron. Its loss produces inconsiderable change in the atomic weight but does change the place of the remaining element in the periodic table, in other words changes it to another element of practically the same atomic weight—a so-called isobar. For instance, Hahn and Mattauch have recently discovered (and their results are being confirmed in the chemical laboratory of the U. S. Geological Survey) that the rubidium of which the atomic weight is 87 (about 25–28 percent of rubidium) changes to strontium of which the atomic weight is also 87. Of this there is in strontium generally only 7.5 percent.[27]

Here we are brought face to face with two of the principal difficulties in the measurement of the age of minerals and rocks by atomic disintegration. How do we know that the elements produced by disintegration were not already there? If this is answered by saying that they have a peculiar atomic weight, then the problem arises, how to find that weight, especially when one has but very small quantities.

The third ray given off is the gamma ray, which is only an X-ray. So far it has not been considered in geologic age determination. Yet its work in penetrating the wrapping and darkening photographic plates led to the discovery of atomic disintegration. But as such rays are known to affect the formation and disintegration of elements they may have to be taken into account sometimes, though preliminary investigation would suggest that they are a very minor factor. Plate 1, figure 2, is a print of a polished piece of radium ore from Great Bear Lake, Canada, made by its own light.

The methods of getting ages of rocks and minerals have been mainly: For the rocks, the amount of helium (alpha-ray product) which has accumulated from the explosion of the uranium and thorium. The lead is very small in comparison even with the few grams per ton of ordinary lead present, and until recently it has been impossible even to attempt to get the proportion of isotopes in the rock lead, as it would involve getting about a gram of lead from a rock which contained less than 22 grams in a ton. Of this only a small portion would be the lead derived from the explosion of the uranium and thorium atoms, perhaps 10 percent.

For instance, Dr. Urry has computed for the "whinsill," a well-known sheet of intrusive basalt that occurs in the British Carboniferous, that the lead derived from the uranium and the thorium would be about 0.049 gram per ton, whereas the actual amount of lead present was 3 to 5 grams per ton. M. F. Conner found similar results in concentrates which he analyzed.

In molten rocks the helium gas was mainly driven off at the time they were molten. Helium derived from the atmosphere can be recognized by the neon which goes with it. The helium might, of course, diffuse. But when the helium is present in such small quantities as a few cubic centimeters per ton of rock, and especially as it is right in the network of a crystalline structure, it does not seem to lose enough to prevent determination of relative age, if work is done on fine-grained basaltic specimens taken fresh and compact, and from a considerable distance below the surface. Results on granitic rocks are unaccountably low.

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[27] Die Naturwissenschaften, vol. 25, no. 12, p. 189, 1937.

On the other hand, in radioactive minerals containing a considerable amount of a radioactive element, the lead ratio is the more significant, and, if there is considerably more helium in the mineral than in the surroundings, the helium diffuses.

The helium methods are then likely to give ages that are too low, and the ratio of lead to the uranium and thorium, if the ordinary lead has not been determined, ages that are too high. Insofar as they check, we can be reasonably sure of not being far off, except for a possibility that the rate of change is markedly different now from what it has been in the past. In the case of the Silver Leaf Mine-Huron Claim region, the age by the Sr (87) : Rb (87) ratio also checks within 10 percent.

For instance, a number of ages of Triassic rocks later than the Carboniferous have uniformly given ages by the helium method less than 200 million years. On the other hand, there are over a dozen analyses of minerals in pegmatites intruded before the Appalachian uplift, and certainly not later than the Carboniferous, which would indicate ages between 200 and 300 million years. Thus, the probability is very great that 200 to 250 million years ago some at least of the Carboniferous coals were being formed.

If a mineral or a rock contains a number of elements disintegrating at known rates to different products, we have an excellent check, provided we can distinguish them and their products. Indeed, if we know the proportions of the products and can be sure their production began at the same time (as will be true, for instance, for the various leads produced by the isotopes of which uranium is composed, of which the most abundant have atomic weights 206 and 207) we can infer the ages, since the lead from older minerals will have a larger proportion of the products of the more rapidly disappearing isotopes.

Prof. A. von Grosse [28] has especially emphasized this, and John L. Rose [29] has computed several ages from the relative strength of the spectral lines of the different leads. Yet, as ordinary lead is a mixture of the same isotopes, the isotope that comes from thorium Pb (208) and a small quantity of an isotope Pb (204), unless we can find how much of it there is by the quantity of Pb (204), the results will be uncertain until there is better agreement as to what isotopes and how much of them uranium contains, and how fast they change. In this field G. P. Baxter and A. O. Nier are actively at work.

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[28] Von Grosse, A., Journ. Phys. Chem., vol. 38, pp. 87–494, 1934; also paper before the Amer. Chem. Soc., Rochester, September 1937.

[29] Rose, John L., Phys. Rev., vol. 50, pp. 792–796, November 1936.

Potassium is radioactive through giving off a beta particle—an electron. As recently as 1933, when Aston wrote Isotopes, although it was recognized that the radioactivity was due to an isotope heavier than the common K (29), it was supposed to be caused by K (41) changing to Ca (41). It has since become apparent that the radioactivity was due to a K (40), not before recognized. This makes no longer applicable some ingenious suggestions of A. Holmes, depending on the recognition of the supposedly relatively rare isotope of calcium Ca (41). The calcium isotope Ca (40) actually is very common. The most that can be said now is that the ratio of calcium to potassium will give a maximum age to rock and mineral and to the earth, as A. Keith Brewer has recently pointed out.[30] Of course, in all minerals that contain potassium there must be calcium, and if there is very little calcium, the maximum may be near the true age.

But to use potassium or rubidium changes, accurate analysis of very small quantities will be needed. The methods of quantitative spectroscopy must be developed. We may look for similar developments with other elements.

PLEOCHROIC HALOS

We are entitled to infer that the rate of disintegration of atoms has not markedly changed during geologic times from the fact that the value of pleochroic halos around minute crystals containing a radioactive element are about the same in the older rocks as in the younger ones, or as in recent artificial preparations. The halos to which I refer have been noticed since the days of Rosenbusch and have been recently studied by D. E. Kerr-Lawson[31] and G. H. Henderson;[32] they are illustrated by plate 2, after Henderson's latest paper. They depend upon the fact that the helium bullets flying off when an atom explodes change the color of the surrounding mineral, which acts as host for the minute specks of zircon or allanite or whatever radioactive mineral may be their source. In particular they affect the iron of the mica, so that, while they are hardly visible when the mica is dark (that is, the light is vibrating parallel to the cleavage), they are much plainer when the mica is light (the light which passes through it is vibrating perpendicular to the cleavage). In other words, the effect is much the same as that produced by these rays on a photographic plate.

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[30] Radioactivity of potassium and geologic time, Science, vol. 86, No. 2226, p. 198, Aug. 27, 1937.

[31] Kerr-Lawson, D. E., Pleochroic halos in biotite from near Murray Bay, P. Q., Univ. Toronto Studies, Geol. Ser., No. 24, Contr. to Canadian Mineralogy, 1927.

[32] Henderson, G. H., A quantitative study of pleochroic halos.—1, Proc. Roy. Soc., ser. A, vol. 145, pp. 563–581, 591–598, 1934; vol. 158, pp. 199–211, 1937.

Now the alpha particles are stopped by collision with other atoms in a short distance (0.03 to 0.04 mm in the mica), and it is found that they are most effective at the end of their flight. Thus they tend to produce a ring of discoloration, if not much overexposed. Moreover, each element gives off particles which have a definite range, or penetrating power; Holmes gives a table of these ranges.[33] The more radioactive the element, the greater is this range; i. e., the more rapidly it disintegrates.

If, as we have said, a mineral contains elements disintegrating at different rates, and uranium is composed of two such elements, the older minerals will contain on the average (or in case of isotopes, certainly) more of the less stable, more rapidly disintegrating element and of its products. Henderson has been trying to determine the ages of halos by the relative strength of the rings, especially of one due to a product, known as actinium C, of a uranium isotope to that of a product of the uranium isotope which produces ordinary radium and a shorter-lived element, which makes the outside ring, known as radium C. He has also studied the thorium rings. It has been very difficult to find mica in which the successive rings are distinct and then to split it fine enough to get a section through the center of the sphere of an alteration (which has a diameter of less than 0.04 mm) instead of taking in a good part of the sphere, in which case the separate rings are not visible. Joly [34] thought that the whole diameter was slightly greater in the older halos, but it was only a thousandth of a millimeter or so. The fact that the diameters of these halos are so nearly the same as those of halos now artificially produced is an excellent reason (taken together with the fact that the more rapidly an element sends off helium bullets—alpha particles—the farther they fly) for believing that the rate of action has not changed substantially.

To be sure, if the few extra long-range particles were too few to make a perceptible darkening during the time of our present experiments but might in a million years, and in the older halos are responsible for the outside diameter, then there might be a slight secular quickening in the discharge of the alpha particles which had been thus disguised.

In order to make any estimates of time, Henderson had to estimate the relative strength of the rings made by the various radioactive elements. This can be done by the microdensitometer, the same kind of instrument which astronomers use in measuring the proportions of elements in the spectra that come from the stars, and J. L. Rose, estimated the proportion of isotopes by working upon a fine line structure, that is, comparing the strength of the lines into which one line of the lead spectrum can be broken by sufficient magnification.[35]

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[33] Nat. Res. Counc. Bull. 80, ch. 2, pt. 4, p. 160, 1931; Age of the Earth, p. 135, 1937.

[34] Joly, J., Pleochroic halos of various geological ages. Proc. Roy. Soc., ser. A, vol. 102, pp. 682–705, 1925.

Aston[36] obtained the proportion of isotope, by using a mass spectrograph in which the atoms shot off from a target pass between magnetic poles which deflect the heavier atoms from their course less than the lighter ones. He registers the atoms on the photographic plate which they strike. In Dempster's[36] improved apparatus the atoms are exposed to a continuous field which swings them around in a great arc and gets them farther apart. But estimations of the strength of lines are limited in accuracy and are likely to be interfered with by lines for other compounds. A. O. C. Nier's present apparatus for the cumulative record of the effect of these atoms promises greater accuracy and uses smaller quantities.

A difficulty already mentioned is in getting the quantity required to make an analysis, a separation of isotopes, and an age determination. Still the quantity needed has steadily diminshed until it is surprising how complete an analysis F. Hecht and L. Kroupa, in Vienna, can make with only 50 milligrams of uraninite, about the weight of a postage stamp.[37] Even with their methods, minerals such as zircon and allanite that have only a little uranium or thorium, often only 2 or 3 percent, offer difficulties, and if the lead in them is only a hundredth part of that, which is the case for Tertiary or younger minerals, it can readily be seen how refined and accurate methods of analysis must be. Moreover, recent work on successive zones of the same crystal have shown a change in composition due to a transfer of material. In comparatively fresh material, that appears to be satisfactory, the uranium seems to be the more soluble as a uranous compound and at least films of secondary uranic yellow compounds are found in radioactive deposits generally. Yet these very studies tend to show that such changes are not often over 10 percent, and that the ages are in a general way correct.

ROCK AGES

As has been said, in rocks there is so much ordinary lead that until the separation of small quantities of isotopes of lead and the identification of ordinary lead, say by the 204 isotope, can be safely accomplished with small quantities, no reliable age determinations can be obtained. But helium has not the same difficulty, if we take compact rocks containing no air and which have been molten. Melting drives out most of the helium and other gases as well. Helium being a gas, is likely to escape, and until a few years ago it was generally accepted that ages by helium would be only an uncertain fraction of those obtained by lead ratios. Since then work by Holmes and Dubey and Paneth and Urry has given results which seemed more reliable and to fit the lead scale more closely.

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[35] Rose, J. L., and Stranathan, R. K., Geologic time and atomic composition of radiogenic lead. Phys. Rev., vol. 50, pp. 792–796, 1936.

[36] Aston, F. W., Mass spectra and isotopes. Longmans, 1933.

[37] Hecht, F., and Kroupa, L., Die Bedeutung der quantitative Mikroanalyse radioaktive Mineralien für die geologische Zeitmessung. Zeitschr. Chem., vol. 106, pp. 82–103, 1936.

But they are not beyond question, and more recent work by Goodman and Keevil under Evans seems to show that while the helium determinations and those of thorium are fairly close, all the previous work on the amount of radium in the rocks may need substantial correction. Specimens from the same dike and therefore of the same age since consolidation, but showing considerable difference in uranium and thorium, have, nevertheless, helium just right to give the same age, within the limit of error of the work. Contamination with atmosphere can be told by the presence of neon. The process requires great skill, involving as it does determination of uranium in quantities of grams per ton, of radium in ten-thousandths of a milligram per ton, helium in cubic centimeters per cubic meter of rock, and thorium also in grams per ton. Methods first developed by Paneth have been perfected by Urry.[38]

If, therefore, we find Devonian traps giving ages between 265 and 300 million years by the helium method, while minerals in Devonian pegmatites with isotopes determined give ages from 277 to 300 million years, since the errors by the helium method are likely to make the ages too low and those by the lead method to make them too high, we may be pretty confident that 275 million years ago was in Devonian time, unless there is a general systematic error not yet located. Thus the ages given by Stille in figure 2 must be somewhat changed.

Thanks to Urry, we thus have the geologic column roughly outlined as far back as there are fossils. In fact, in the Noranda mine we find rocks that seem to be twice as old. It remains to test the country rock where the minerals in the pegmatite seem to be 1,800 million years old, as near Winnipeg. In this region where Harwood writes of very old "Prekeewatin tonalite," the recent work of Hahn and Mattauch on a rubidium-bearing mica and the change from Rb (87) to Sr (87) leads to an age of 1,700 to 2,000 million years,[39] which agrees with the age determined by analyses by Ellsworth, Hecht, and Kroupa of uraninite and monazite, all of which indicate an age of about 1,800 million years.

Thus, in spite of difficulties, progress is being made, as results are obtained from smaller and smaller quantities, and as the methods of separating and determining isotopes are improved.

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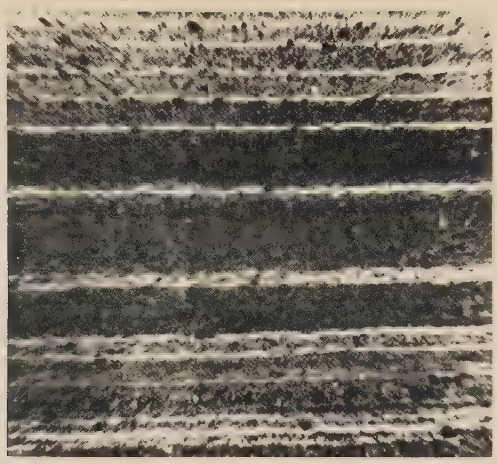
[38] Urry, W. D., Helium and the problem of geologic time. Chem. Rev., vol. 1, pp. 306–343, 1933. Ages by the helium method. Bull. Geol. Soc. Amer., vol. 46, pp. 1105–1120, 1935; vol. 47, pp. 1217–1234, 1936.

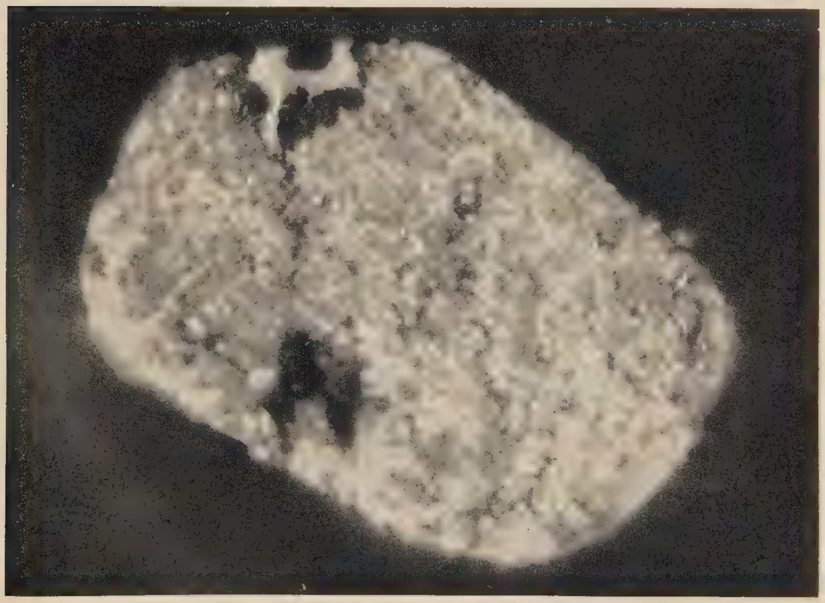
[39] Personal communication. See also Die Naturwissenschaften, vol. 25, No. 12, p. 189, 1937.



After Bradley

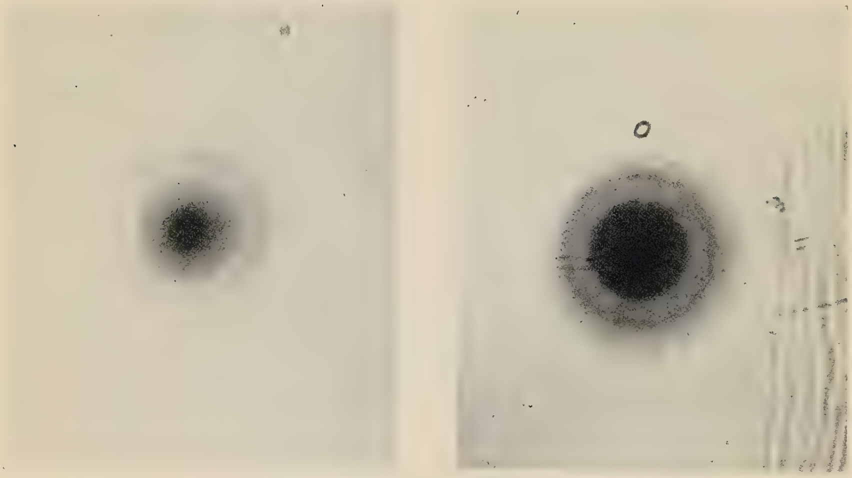
1. VARIATION IN YEARLY BANDS (VARVES).

Fine-grained limey sandstone of upper part of Green River formation. Enlarged 27 diameters.



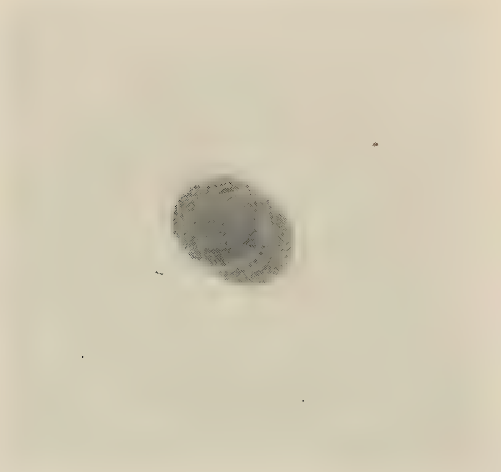
2. RADIOGRAPH OF POLISHED PIECE OF GREAT BEAR LAKE RADIUM ORE (PITCHBLENDE) MADE BY ITS OWN ACTION ON A PHOTOGRAPHIC PLATE.

Six days' exposure.



1, 2. MICROPHOTOGRAPHS OF THORIUM HALOS AFTER HENDERSON'S LATEST PAPER.

The outside ring has a radius of 0.0418 mm. (Proc. Roy. Soc. London, vol. 158, opp. p. 208, pl. 9.)



After D. E. Kerr-Lawson

3. MICROPHOTOGRAPHS OF OVERLAPPING URANIUM HALOS.

Compare the halos D. E. Kerr-Lawson published in University of Toronto Studies, Geological Series, No. 24, pls. 2, 4, and No. 27, pls. 3, 4.

THE EARTH'S INTERIOR, ITS NATURE AND COMPOSITION [1]

By Leason H. Adams
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[With 2 plates]

Two events in the last few years have made possible a noteworthy advance in our knowledge of the earth's interior, and have for the first time extended our ideas on this subject definitely beyond those of the early Greek philosophers. The two aids to progress were, first, the precise measurement of the elastic properties of rocks and, second, an improved technique in seismology which permitted the accumulation of reliable data on the speeds of waves from near and from distant earthquakes. Other researches in geophysics have played an important, although secondary role, and have promoted a steady improvement in our knowledge of the earth as a whole. It is the object of this communication to summarize briefly the present notions concerning the earth's interior and the steps by which the information has been obtained.

ORIGIN OF THE EARTH

A discussion of the interior of the earth should properly start with a consideration of its origin and its place in the universe. Geophysics begins with cosmogony. Our earth is a spherical body about 8,000 miles in diameter floating in nearly empty space. Its nearest neighbor, the moon, is a quarter of a million miles away. Together, they revolve around the sun at a distance of some 90 million miles. The other planets of the solar system circle around the same sun, which, although by far the largest object in the system, is merely a star like countless others that dot the sky, and is, as stars go, a rather small and insignificant one. Separated from the sun by enormous distances are the other stars of our galaxy, which has a disklike form and an extent of at least 50,000 light years, and is merely one of the innumerable spiral nebulae scattered irregularly through space at an average distance of perhaps 1,000,000 light years.

On so vast a scale, our earth, a tiny planet accompanying a small star, seems to dwindle into insignificance, but it is after all the place where we dwell and have our being, and for us it has the importance attaching to a great object, which, except for the surface layers, is as yet unexplored.

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[1] An address delivered at the Administration Building, Carnegie Institution of Washington, October 27, 1936. Reprinted by permission from the Scientific Monthly, vol. 44, pp. 199–209, March 1937.

It is now generally accepted that the earth was created from the parent sun about 2,000 million years ago through tidal disruption by a passing star. The subsequent liquefaction and solidification of the detached mass of glowing gas formed the juvenile earth. This notion, advanced by Jeans and Jeffreys, is quite different from that involved in the nebular hypothesis of Laplace, according to which the sun was originally surrounded by a rarefied nebula which rotated about the central mass. As the nebular material cooled it was supposed to contract and increase its speed of rotation, until finally the centrifugal force was sufficient to detach a ring of material, which condensed to form a planet. Although accepted for many years, the hypothesis was finally discarded on purely mathematical grounds. The theory now in favor also differs in many important details from another tidal theory, the planetesimal hypothesis enunciated by Chamberlin and Moulton. This was the first to account satisfactorily for many of the major features of the solar system, and involved the formation, from the tidal protuberances, of swarms of solid fragments (planetesimals), which coalesced around various nuclei and thus produced the planets. The significance of the modern theory, for the purposes of this discussion, lies in the supposition that *the earth for a brief time after its creation was entirely molten,* well stirred by convection, and, to the extent that the component substances were miscible in the liquid state, quite homogeneous in composition.

NATURE OF THE PROBLEM

The composition and state of the earth's interior has long remained a problem of great difficulty. It is at the same time a subject of lasting interest, alike for the scientist and for the layman. There is always a certain fascination in the mysterious and unknown, especially when it appears impossible to solve the problems that are presented. If it should seem a hopeless task to learn anything about the interior of the earth, we might profit by adopting that philosophical attitude toward the origin of the earth and the nature of its interior which was expressed by Barrell [2] as follows:

> The history of the earth is read in the rocks which have been thrust up by internal forces and beveled across by erosion. The nearer events are clearly recorded in the sequence and nature of the sedimentary rocks and their fossils. But the oldest formations have been folded, mashed, and crystallized out of all resemblance to their original nature, and intruded by molten masses now solidified into granite and other igneous rocks. Fossils, the time markers of geology, if once existent, have been destroyed, and, as in the dawn of human history, vast periods of time are dimly sensed through the disordered and illegible record.
>
> This crystallized and intricately distorted series of the oldest terrestrial rocks tells of an earth surface on which air and water played their parts much as now.

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[2] Barrell, Joseph, ch. I in The Evolution of the Earth, by R. S. Lull and others. New Haven, 1919.

But it was a surface repeatedly overwhelmed by outpourings of basaltic lava on a vaster scale than those of later ages, and the crust was recurrently broken up and engulfed in the floods of rising granitic magmas. Here the geologic record begins, but the nature of its beginning points clearly to the existence of a prehistoric eon. At the farther bounds of this unrecorded time, forever hidden from direct observation, lies the origin of the earth.

But the mind of man will not be baffled. Since he may not see directly he will see by inference. Convergent lines of evidence derived from various fields of knowledge may be followed part way toward this goal, like those rays perceived through the telescope on the full moon near the margin of its visible hemisphere, which converge toward craters on the side of the moon that no eye shall ever see.

Developments in various branches of science during recent years have enabled us to draw a picture showing, as yet none too clearly, what the interior is like. Any progress that may have been made is due to the joint effort of many investigators, in the laboratory and in the field. The measurements and observations have been interpreted through the medium of physics, of chemistry, and of mathematics. The important part played by these exact sciences in the study of the earth was recognized many years ago. For example, the Advisory Committee on Geophysics of the Carnegie Institution of Washington in 1902 stated in its report: "The phenomena presented by the earth are the historical products of chemical and physical forces."

SOURCES OF INFORMATION

We now proceed to discuss briefly the various sources of information concerning the earth's interior and to list the more important bits of evidence, which may be joined together to give us a notion of the constitution of the earth as a whole.

The surface of the earth has been thoroughly explored, and what lies just below the surface of the land masses has been carefully and patiently studied by geologists for many years. Thanks to the dissection of the surface by erosion, notably in deep canyons, we are able to learn much about the materials down to a depth of several thousand feet, so that we now have an accurate picture of the rock masses that lie below the superficial layer of soil and sedimentary rocks. Underneath this thin veneer there is mainly igneous rock, that is, rock that has solidified from molten magma. According to Clarke's estimate, the outer 10 miles of the earth consist of 95.0 percent igneous rock, 4.0 percent shale, 0.75 percent sandstone and 0.25 percent limestone. The labors of the geologist have given us a store of information concerning the structure and mineral composition of rocks and the interrelations of the various formations. Although there are an overwhelming number of rock types, with respect to composition and texture, curiously enough a predominating amount of the visible igneous rock is either granitic or basaltic. The land surfaces occupy only about one-fourth of the area of the globe. Unfortunately little as yet is known about the rocks of the remaining three-fourths, although something may be inferred from the geology of the ocean bottom by observations on oceanic islands. Direct sampling of the ocean floor has been limited to a few inches in depth until quite recently, the depth having now been extended to several feet.[3]

Supplementing the facts of geology, the phenomenon of volcanism yields important information concerning what we may call the near interior. The existence of volcanoes and the outpouring of vast quantities of hot gases and molten lava furnish direct and striking evidence of conditions many miles below the surface. Additional information of value has been supplied by measuring the temperature of lava lakes, of lava flows and of the gases emerging from fumaroles. Further evidence of a hot interior is derived from the measurement of temperature in deep mines and boreholes. The temperature increases steadily with depth, but for reasons yet unknown the temperature gradient varies within wide limits from place to place in the earth. It may increase as much as 1° C. for each 18 meters or as little as 1° C. for over 100 meters. According to Van Orstrand,[4] the greatest depth attained in any boring is 12,800 feet (in Upton County, Tex.); the highest temperature that has been measured is 118° C. in California at a depth of 9,000 feet.

Astronomy yields data of high precision concerning the motion of the earth, from which can be calculated its moment of inertia. The precession of the equinox was discovered by the Greek astronomer Hipparchus in 134 B. C. From the accurately known value of the constant of precession, it follows that the moment of inertia of the earth about the polar axis is 8.06×10^{44}g cm^2. This is a quantity that depends on the distribution of density within the earth. For a given mass, and for a given mean density, the moment of inertia depends on the distribution of light and heavy substances; if there is heavy material at the center and light material at the surface, the moment of inertia would be considerably less than if the central density were smaller than that of the surface. The moment of inertia of a body may be described qualitatively as its tendency to continue spinning when once it has been set in motion. It is obvious that a fly-wheel loaded at the center will spin less persistently than if the same load were fastened to the rim. Similarly, the known moment of inertia of the earth allows us to make important deductions concerning the mass or density at various positions from surface to center.

By far the most direct and definite evidence concerning the interior of the earth is supplied by earthquake waves, especially in combination with laboratory measurements on various rocks and minerals. The story has been told before, but it will bear brief repetition. When an earthquake occurs, elastic vibrations of various kinds are generated.

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[3] Piggot, C. S., Bull. Geol. Soc. Amer., vol. 47, pp. 675–684, 1936.

[4] Van Orstrand, C. E., personal communication.

One variety travels along the surface and is responsible for the damage caused by large earthquakes. More important for the present purpose are the two varieties that pass through the body of the earth. One of these "through-waves" consists of longitudinal vibrations, analogous to ordinary sound waves in air; the other consists of transverse vibrations, more nearly akin to light waves. Their formation is in accord with the conclusion from the theory of elasticity that any disturbance in an elastic isotropic material should give rise to the two kinds of vibrations, traveling with velocities depending only on the density and elastic constants of the material at each point. Earthquake waves, which have passed through the earth, are recorded by the delicate instruments of the seismologist, who is able to distinguish the several types of waves and to tell with high precision their time of arrival at various stations. From the observations we may construct for each kind of wave a "travel time"-distance curve, which shows for any distance the time required for the vibrations to pass from the earthquake center to the recording instrument. The mathematician is now called upon. After subjecting the curve to a remarkable and intricate mathematical analysis he finds the shape of the path along which the wave travels—it turns out to be curved—and finds also the velocity at each point of its path, that is, the velocity at the various depths to which the wave has penetrated in its journey through the earth from focus to station. The recent careful determinations of Repetti [5] are shown in figure 1. The particular value of this velocity-

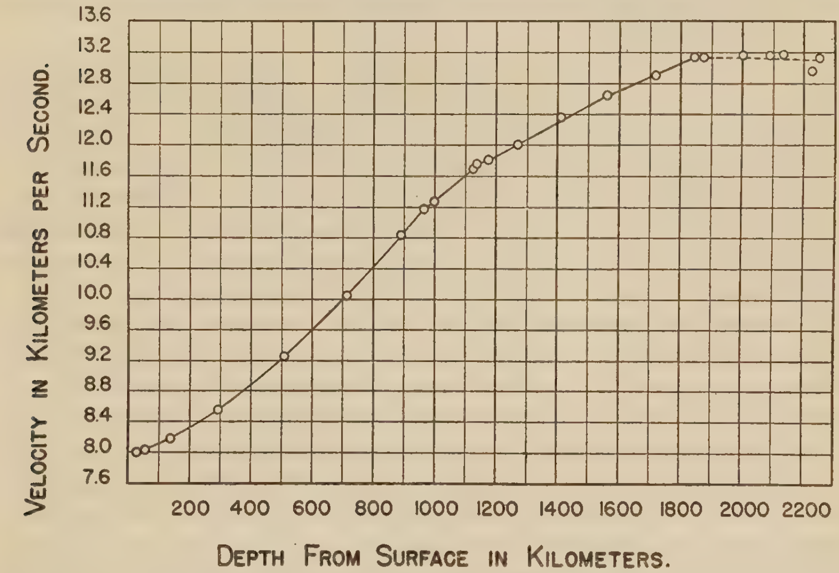

FIGURE 1.—Velocity-depth curve (after Repetti). Such curves supply direct evidence concerning the nature of the earth's interior.

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[5] Repetti, Wm. C., Dissertation, St. Louis University. Printed in Manila, 1930.

depth relation lies in the fact that solely from laboratory measurements of the elastic constants of rocks (to which reference will be made later) we may calculate the wave velocity in various types of rocks, and thence, by comparison with the known velocities at several depths below the surface, make important deductions concerning the nature and composition of the material within the earth. It is as if the earthquake waves, upon arriving at the surface, carry with them a message telling not only how long they have been on the way and how deep they have penetrated, but also how fast they traveled at each point of their path, and finally the nature of the material through which they have journeyed. To be sure, the messages are in code, but happily the code has been deciphered by the ingenious devices of the mathematician.

Turning now to those laboratory measurements that pertain to the present subject, we note first the constant of gravitation, originally determined by Cavendish in the eighteenth century. The most recent published result, that of Heyl,[6] is 6.67×10^{-8} in absolute units. From the measured constant of gravitation we know at once the total mass of the earth, and thence by combination with its volume, the average density of the globe. The value obtained, 5.52, is a very important one to which reference will be made later.

The chemical composition of the rocks in or near the earth's surface has been subjected to exhaustive investigation. It is a striking fact that, although about 1,000 different minerals are known, the important and essential igneous rock-forming minerals number only about a dozen, and that although some 90 chemical elements have been found in or on the earth, 11 elements make up 99½ percent of the earth's layers. These elements in order of their abundance are: oxygen, silicon, aluminum, iron, calcium, sodium, potassium, magnesium, titanium, phosphorus, and hydrogen. The above conclusions are based on the studies of Washington and others of nearly 10,000 chemical analyses of rocks, which show also that the average igneous rock found at the surface of the earth corresponds to a granite or granodiorite.

Of especial significance is the composition of meteorites. As a result of many analyses of these strange visitors from outer space we now know that they consist largely of impure metallic iron and basic silicates approaching olivine in composition. Absent, or present only in minor amounts, are the characteristic constituents of granite, such as lime, alumina and the alkalis.

An indispensable item in the list of factors from which we hope to reach definite conclusions concerning the earth's interior is the compressibility of rocks. One of the earliest grants of the Carnegie Institution of Washington was to F. D. Adams, at McGill University, for the purpose of measuring the elastic constants of typical rocks.[7] The results obtained were of great interest and value, although the method used was an indirect one and the maximum pressure that was applied to the rock specimens was only a few hundred atmospheres. Subsequently attempts were made by several investigators to measure the cubic compressibility of rocks subjected to pure hydrostatic pressure. This sort of measurement is beset with many difficulties. The effect of pressure on the volume of solids is very small. For most rocks it is between one and two parts per million per atmosphere, and it is desired to measure this small effect with an accuracy of 1 or 2 percent. Satisfactory results were obtained several years ago at the Institution's Geophysical Laboratory by the use of high hydrostatic pressures—10,000 atmospheres or more. High pressure, under hydrostatic conditions, has three important advantages: First, because the pressure conforms more nearly to the conditions at great depths below the surface of the earth; second, because the volume-changes, which are so small when only one atmosphere is available, are multiplied 10,000 times; and third, because by the use of high pressures we avoid the irregularities that appear at low pressures, especially with coarsely crystalline materials.

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[6] Heyl, P. R., Bur. Standards Journ. Res., vol. 5, p. 1243, 1930.

For these measurements the so-called piston-displacement method was used. The specimen, usually cylindrical in form, was placed inside a thick-walled cylinder, or bomb, of special steel, where, entirely surrounded by a thin liquid, it was subjected to the desired pressure. A piston with a leak-proof packing was forced into the bomb by means of a press and the pressure thus built up. A general view of the apparatus used at the Geophysical Laboratory for measuring the compressibility of rocks is shown in plate 1. The amount of movement of the piston is obviously a measure of the volume-change of the material within the bomb. Therefore, by recording the motion, or displacement, for a series of pressures, and correcting for various factors such as the compressibility of the liquid, we obtain finally the compressibility of the specimen.

Although it would be desirable to have similar direct measurements of the rigidity of rocks, a substitute is afforded by the above-mentioned seismologic data, which show that the material at considerable depths is sensibly isotropic and that the elastic constant called Poisson's ratio has the nearly constant value, 2.7. This justifies the use of a simple relation in the theory of elasticity to calculate the rigidity of rocks at high pressures from the compressibility measurements, and thence to calculate the velocities of the transverse and longitudinal vibrations.

Over a period of several years many such measurements and calculations have been made on numerous varieties of granite, diabase and other rocks, and on the common rock-forming minerals. Plate 2 is a photograph of a portion of the specimens that have been investigated. The immediate conclusions from the results were first, that typical rocks had a much lower compressibility, and hence a much higher wave velocity, than had previously been supposed; and second, that except for very low pressures the compressibility of a given rock was merely the average of the compressibilities of its component minerals.

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[7] See Adams, F. D., and Coker, E. G., Carnegie Inst. Washington, Publ. No. 46.

The above-mentioned results were obtained at or near room temperature. Quite recently Birch and Dow at Harvard have been able to carry out measurements at elevated temperatures and thus to supply information concerning the effect of temperature on elasticity and wave speed in rocks.[8]

Brief mention will be made of one other experimental research, which is pertinent to the general subject before us. This is an investigation of the effect of high pressure on the critical temperature at which iron loses its magnetism. It was carried out as a joint effort of two branches of the institution, the department of terrestrial magnetism and the geophysical laboratory. At or above 768° C., iron loses its strong magnetic properties. Any masses of metallic iron within the earth are subjected to the combined effect of high pressures and temperatures. In order to learn something as to the possibility that deep-seated metallic iron, despite a presumably high temperature, should still be strongly magnetic, measurements of critical temperature of magnetization of iron and other ferro-magnetic materials at pressures up to 4,000 atmospheres were carried out. The final result, that the effect of pressure on the critical temperature was practically nil, or probably no greater than 0.001° C. per atmosphere (for pure iron),[9] will be referred to presently in connection with the core of the earth.

THE INTERIOR OF THE EARTH

The observations and experiments that have been described have not been intended merely as a partial list of unrelated facts in the field of geophysics. They are the main clues by which we are enabled to solve, at least partially, the problem of the structure of the earth's interior. We are now quite certain that the earth consists of three principal regions or zones, the core or central region, the crust or superficial layer, and the intermediate zone.

That the material of the earth near its center must be very heavy was one of the earliest conclusions and an excellent example of deductions concerning the interior. Since the average density of the earth as a whole is 5.5, as determined from the measured constant of gravitation, and since the average density of rocks found at the surface is only about 2.8, it is obvious that the central density must be much higher than 2.8—perhaps 8 or 10 or 12—in order for the average to come out right. This high density in the central region might be due to either of two causes: (1) The squeezing of ordinary rock into a much smaller volume under the enormous pressure due to the weight of superincumbent material, or (2) the presence of some other, intrinsically heavier, substance such as a metal. The first alternative was eliminated by using seismologic data to tell us the compressibility of rocks at great depth and then computing the amount by which the volume of silicate rocks could be reduced at depths well toward the center. The maximum by which the density of the material could be increased turns out to be surprisingly large, but entirely inadequate for giving the required average density of the earth. We must conclude, therefore, that it is impossible to account for the high density of the earth by compression alone, and that at and around the center there is a considerable amount of an intrinsically heavy substance. The only reasonable choice is metallic iron. This element is the fourth in order of abundance in ordinary rocks, it is also abundant in the sun as shown by the spectroscope, and in both the metallic and combined form it is the dominant constituent of meteorites. By analogy with meteorites we should expect that the core would not be pure iron but rather an alloy of iron with several percent of nickel. The notion of an iron core is not a new one; it was suggested by Dana in 1873, and developed by Wiechert and others in later years. Still earlier the earth was considered to be a great ball of granite, chemically homogeneous throughout, but we have now passed beyond what may be called the granitic era in geophysics, and our present convictions are based on quantitative evidence of the presence of some heavy material at the center.

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[8] Birch, Francis, and Dow, Richard B., Bull. Geol. Soc. Amer., vol. 47, pp. 1235–1255, 1936.

[9] Adams, L. H., and Green, J. W., Phil. Mag., vol. 12, pp. 361–380, 1931.

We may therefore speak with confidence of an iron or nickel-iron core the diameter of which is fixed by seismologic data at 6,400 kilometers, or a little more than one-half the diameter of the earth, and confirmed by the moment of inertia determined by astronomical observations. The core is plastic rather than rigid, since it does not transmit transverse earthquake waves; it is nonmagnetic and therefore has no appreciable influence on the earth's magnetism; and the pressure at its center, as is easily calculated, reaches the enormous value, 3,200,000 atmospheres. We know the core to be very hot, but it has not yet been possible to arrive at an entirely satisfactory estimate of the central temperature. From considerations connected with the origin of the earth, the conclusion has been reached [10] that the temperature in the far interior is of the order of 3,000° C.

Although the existence of an iron core is generally accepted by those who have interested themselves in the subject, a few investigators have doubted the validity of this conclusion. One, for example, prefers to explain the high central density by the combination of atoms under the conditions of high pressure and temperature to form heavier atoms of various kinds. Others have inclined to the belief that under sufficiently high pressures the structure of all solids will collapse, leaving a material of the same chemical composition and greatly increased density.

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[10] Personal communication from Dr. Ross Gunn.

This reminds one of the heated discussion carried on some years ago in the columns of a magazine devoted to popular science, as to whether the water at the bottom of the ocean was as dense as cast iron. One faction contended that engineering data showed that materials or structures subjected to sufficient compression in a testing machine invariably failed by crushing, and that at considerable depths in the ocean the water would crush, or cave in upon itself, and thus become as dense as a heavy metal. The principle that was overlooked in this contention was that it is relatively very difficult for pure hydrostatic pressure to make a structure collapse. It is true that we must be on guard against applying the experience and conclusions pertaining to a limited range of pressures and temperatures to the extreme conditions prevailing in the interior of the earth.

On the other hand, various considerations indicate that the postulated transmutation of elements and collapse of crystal structure will take place only under pressures and temperatures of a higher order of magnitude than those existing in the earth, that is to say, in the interior of stars rather than planets.

Passing over the intermediate zone for the moment, let us turn our attention to the outer layer, commonly called the crust. This term dates back to the time when the earth was thought to consist of a thin solid crust surrounding a molten interior. But the notion of a true crust floating on a thin liquid is now abandoned, although the word is still used to designate the outer layer, perhaps 40 or 50 kilometers thick, with properties very different from those of the material below it.

From geologic studies it has long been known that the accessible part of the crust consists largely of granite. When the measurements of the compressibilities of rocks, already referred to, were made and the velocity of longitudinal vibrations in typical granites found to be 5.6 kilometers per second, it was therefore a source of gratification to find that this was precisely the speed found by the seismologist for the longitudinal waves in the outermost parts of the crust. From seismologic data we know that this granitic layer varies in thickness from place to place. In continental areas it may be as little as 10 kilometers or as much as 30 kilometers in thickness, while in the great ocean basins it appears to be entirely missing.

Underneath the granitic layer the crust, as indicated by the velocity of earthquake waves passing through this region, is basaltic in composition. There is some evidence for a transition layer intermediate in composition and position, but apparently the crust consists largely, if not entirely, of the granitic and basaltic layers.

By the mathematical theory of heat conduction the temperature throughout the crust may be estimated if three principal factors are known. These are (1) the age of the earth, (2) the average amount of radioactive substances in the superficial rocks, and (3) the temperature gradient at the surface. The age of the earth—that is, the time that has elapsed from the initial solidification to the present time—is probably not far from 2,000 million years, since minerals have been found, whose age as determined by the lead-uranium ratio is 1,500 million years, and since from astronomical considerations an upper limit of 3,000 million years is indicated. The average amount of radium in the rocks found at the surface is about 3 parts in a million million and the average temperature gradient in undisturbed regions is 0.03° C. per meter. Although these items are all subject to considerable uncertainty, they allow us to construct a useful curve, showing how temperature varies with depth. Especially striking is the conclusion that below about 300 kilometers the temperature is nearly the same as it was originally; the greater part of the earth is now as hot as it was when solidification first took place.

The accessible portion of the crust is almost entirely crystalline. Glassy or amorphous material is comparatively rare. Whether the deeper parts of the crust are crystalline or glassy is a question upon which there is not yet complete agreement. It is worth while to note that the question cannot be answered by referring to the temperature-depth curve already mentioned, because the only such curves that have been constructed were based on the supposition that the termination of the era of free convection and the initial cooling of the earth as a solid body were coincident with the freezing of the molten magma.

The intermediate zone 2,000 miles in thickness extends from the bottom of the crust to the top of the iron core (see fig. 2). Its striking features are the major discontinuities in the velocities of earthquake waves at the upper and lower boundaries. Passing from the crust down through the upper surface of this region, longitudinal waves suddenly increase their speed to 8 kilometers per second. The laboratory measurements on the elasticity of rocks, mentioned above, indicated that only two kinds of rock could support so high a velocity at the moderate pressures appropriate at a depth of about 50 kilometers. These are dunite and eclogite, rocks that are found in few places at the surface of the earth. Weighty evidence pointed to the first of these as the more probable constituent of the intermediate zone, and the conclusion was drawn that the shell consisted of this olivine rock and that therefore the whole earth, except for the iron core and the relatively thin crust, was made up entirely of magnesium iron orthosilicate. It followed that only four elements, silicon, oxygen, magnesium and iron, composed the bulk of the earth's substance, all the other elements being present in minor amounts.

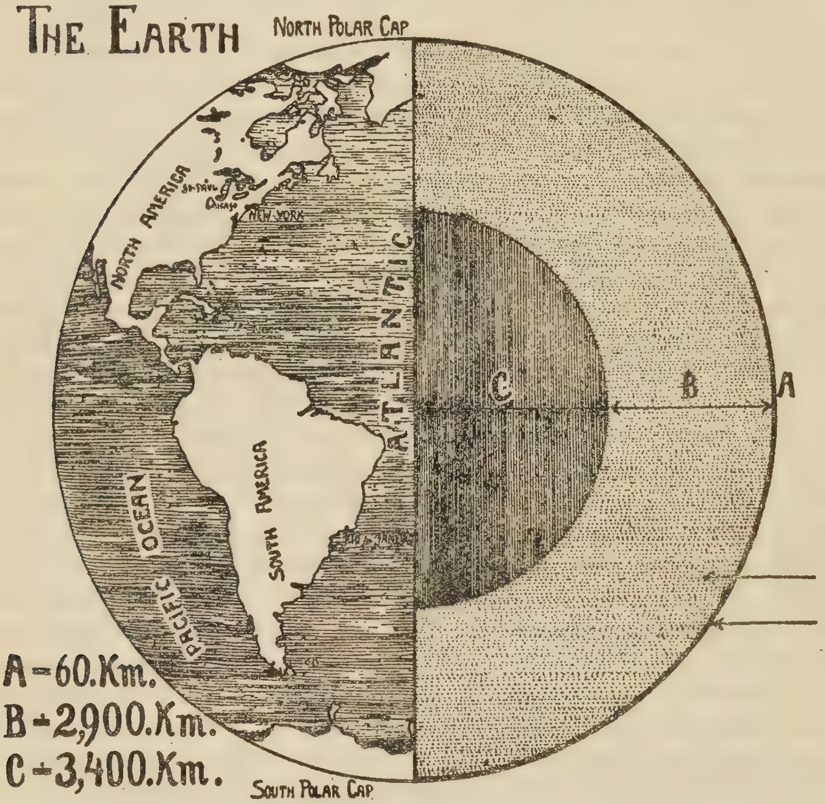
THE EARTH
NORTH POLAR CAP
NORTH AMERICA
ST. PAUL
CHICAGO
NEW YORK
ATLANTIC
PACIFIC OCEAN
SOUTH AMERICA
C
B
A
A-60.Km.
B-2,900.Km.
C-3,400.Km.
SOUTH POLAR CAP

FIGURE 2.—Section through the earth. (After Mohorovičić.) *A* is the crust, *B* the intermediate zone, and *C* the central core.

The force of this conclusion has been weakened somewhat by the recent measurements of Birch and Dow, mentioned above, on a specimen of diabase from Vinal Haven. The result obtained for the compressibility leads to a wave velocity equaling that found in the upper part of the intermediate layer, and thus appears to invalidate the argument that the presence of dunite or peridotite in this region is necessary in order to account for the observed velocities of earthquakes below the bottom of the crust. The method used was a linear one, the cubic compressibility being inferred from the change in length of a small rod exposed to pressure, whereas at the Geophysical Laboratory the volume-change, being measured directly, is independent of the degree of isotropy of the material. In view of the fact that the two methods agree remarkably well for nonporous substances such as silica glass and also for the porous rock, limestone, the writer prefers to accept the results of direct volume-change measurement and the conclusions based thereon, at least until measurements by the linear method are made on specimens of diabase cut in three mutually perpendicular directions, and until further measurements by both methods on the same samples of rock become available.[11]

From observations on the tidal deformation of the surface, the earth has long been known to be as rigid as steel, and from seismologic data we find that from crust to core the rigidity increases steadily with increasing depth. It is very clear, therefore, that the earth as a whole is "solid"; but whether its substance, particularly in the intermediate zone, is crystalline or glassy is more difficult to decide. From what information we have it does not seem possible that any silicate glass of a composition favorable for remaining permanently in the glassy state can support the requisite wave velocities. Although there may be, and probably are, shallow zones or limited regions of glassy material, the weight of evidence, in the writer's opinion, seems to favor crystallinity for practically the entire silicate part of the earth. This is a subject for which admittedly there are decided differences in the viewpoints of various investigators. Lack of space prevents a complete discussion of the subject at this time.

Many circumstances, concerning which there is at the moment insufficient time for discussion, indicate that the early history of the earth was as follows: The primitive molten magma consisting mainly of magnesium iron silicates with smaller amounts of other oxides, including water, together with a considerable amount of metallic iron, first separated into two layers—molten iron below and silicate magma above. The silicate layer then began to crystallize at the bottom. As the solid layer increased in thickness, the minor constituents, including water, were concentrated to a greater and greater extent in the remaining liquid. Finally, when the liquid layer had been reduced to a thickness of a few tens of kilometers, and was much richer in the originally minor constituents, the crust of the earth was formed.

One of the most cogent reasons for believing that the earth is crystalline is that in no other way can we easily account for the fact that the crust differs so markedly from the interior. Granting that the earth was once molten and well stirred, we apparently must admit that the separation into zones on so large a scale took place either by the falling of a heavy insoluble liquid to the bottom (thus producing the iron core) or by the residuum of a process of crystallization, this residuum becoming the crust.

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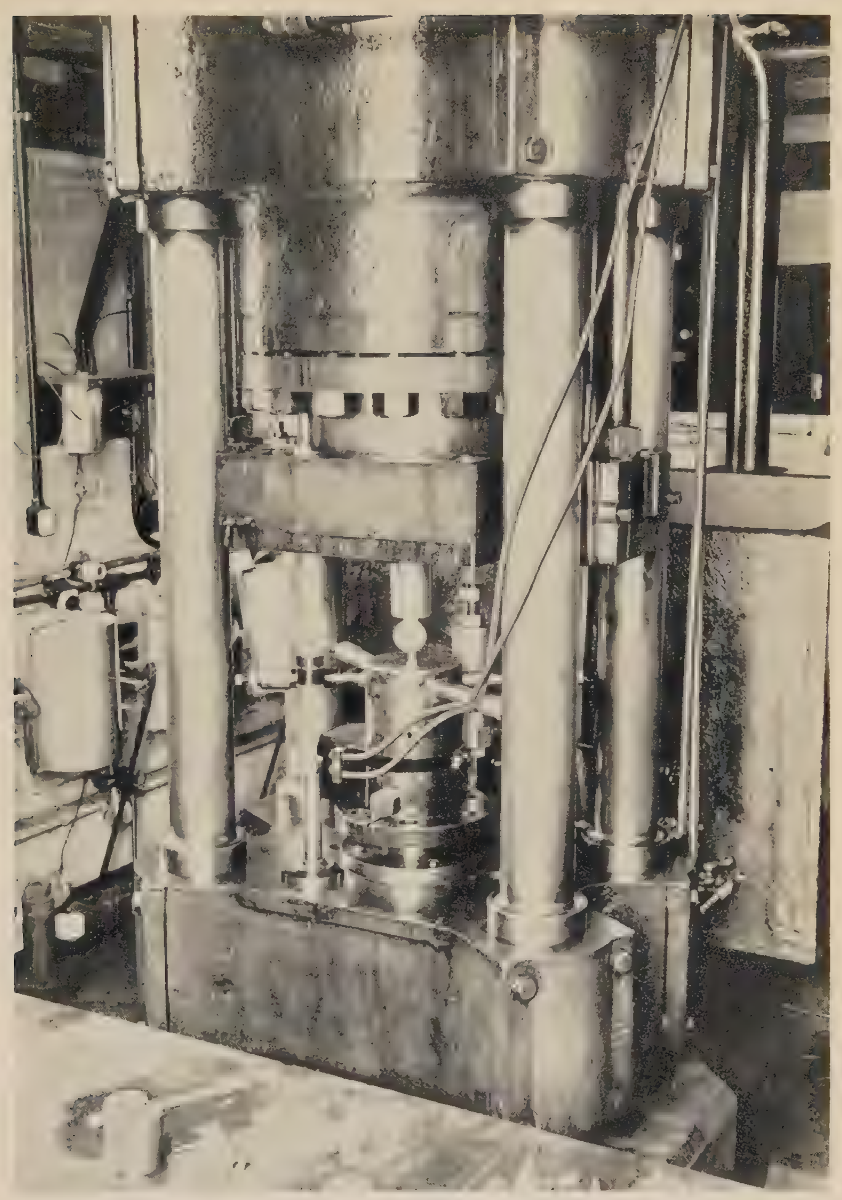
[11] *Footnote added in proof.* Recent measurements by Birch and Bancroft (Journ. Geol., vol. 46, p. 126, 1038) confirm the compressibility results obtained at the Geophysical Laboratory.

CONCLUDING REMARKS

The problem of the earth's interior has not yet been solved. Although much is known about conditions far within the earth the interior still holds many mysteries. An explanation of the mechanism by which deep-focus earthquakes occur is lacking, and we have no clues as to the underlying cause of the numerous minor discontinuities in the earthquake velocity-depth curves. Better knowledge of the temperatures within the earth would be of great utility and, especially, some basis for a more precise estimate of the original temperature of the molten earth. A general understanding of the great intermediate zone is essential before we can make satisfactory progress in investigations of the crust.

But although much remains for the future, we are able to point to a number of definite accomplishments during the past several years. These are (1) precise measurement of the elastic constants of rocks and the determination of the speeds with which elastic waves will travel through them; (2) the identification of the upper half of the crust as a granitic layer; (3) a demonstration that the core of the earth contains a heavy material such as iron; (4) an explanation of the two major discontinuities within the earth in terms of the elastic constants of typical rocks; (5) the supplying of strong evidence that large masses of iron may exist in the interior without influencing the earth's magnetic field, and (6) the establishment of an improved temperature-depth curve for the crust and the region immediately below it.

In attempting to paint a picture of the deeper parts of the earth, the best we can do at present is to draw the outlines. Perhaps future developments may enable us to make a bolder drawing and even to fill in something of form and color.



SHOWING THE "BOMB" AT THE GEOPHYSICAL LABORATORY OF CARNEGIE INSTITUTION.

This "bomb" consists of a cylinder of special steel, 6 inches in diameter and 14 inches high. It is solid except for a tubular hole, ⅝ of an inch in diameter and about 10 inches long, which is fitted with a leak-proof piston through movement of which a pressure equivalent to 240,000 pounds to the square inch can be obtained. This apparatus was devised for investigating the behavior of rocks and solutions under extreme pressures comparable to those that prevail at great depths in the earth.

A PORTION OF THE CYLINDRICAL SPECIMENS ON WHICH COMPRESSIBILITY MEASUREMENTS BY THE PISTON DISPLACEMENT METHOD HAVE BEEN MADE

ORIGIN OF THE GREAT LAKES BASINS[1]

By Francis P. Shepard

University of Illinois

INTRODUCTION

The time-honored hypothesis of glacial excavation as the principal cause of the Great Lakes basins appears to have fallen into disrepute. Most of the latest textbooks of geology and physiography either fail to mention a cause for these greatest of the world's fresh-water lakes or state merely that the basins are the product of land warping, glacial erosion, and glacial deposition. A number of writers have questioned the power of ice in continental glaciers to produce deep basins[2] and have given reasons for believing that other factors were more important. However, for one interested in the ice-erosion hypothesis the greatest surprise is to be found in a recent article regarding the bathymetry of Lake Michigan.[3] The writer of that paper boldly discussed the origin of the basin without even mentioning the possibility that glacial erosion might have been a factor. It is time that someone challenged this growing neglect of the glacial-erosion hypothesis before it reaches an undeserved state of senility. The present writer became interested in the problem through the study of submarine topography and particularly through comparisons made of the bathymetry of the Great Lakes with that of the continental shelves and inlets in glaciated territory.

OBJECTIONS TO ICE EROSION

In regard to the Great Lakes the best statement of the objections of ice erosion is to be found in Thwaites' Outline of Glacial Geology.[4]

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[1] Reprinted by permission from the Journal of Geology, vol. 45, no. 1, January-February 1937.

[2] Fairchild, H. L., Ice Erosion Theory a Fallacy, Bull. Geol. Soc. Amer., vol. 16, pp. 13–74, 1905; Spencer, J. W., Origin of the Basins of the Great Lakes of America, Amer. Geol., vol. 7, pp. 86–97, 1891; Taylor, F. B., Study of Ice-Sheet Erosion and Deposition in the Region of the Great Lakes, Bull. Geol. Soc. Amer., vol. 22, p. 727, 1911; Thwaites, F. T., Outline of Glacial Geology, 1st ed., pp. 42–44, 1927 (2d ed., p. 20, 1934). This excellent treatise on all phases of glaciation provided much information used in preparing the present article.

[3] Evans, O. F., Bathymetric Studies of the Lake Michigan Basin, Geog. Rev., vol. 25, pp. 667-671, 1935.

[4] Op. cit. The first edition contains a more complete statement, although the second edition is more moderate in its condemnation of glacial erosion.

He calls attention to islands of weak rock in the Lake Superior Basin. He notes that the basins are too wide to be properly described as U-shaped, and he questions the existence of hanging valleys along the margins. Furthermore, he refers to similar basins which extend across the direction of ice movement and to neighboring basins in Wisconsin which are "explicable only as depressed parts of river valleys." He calls attention to the numerous glaciated surfaces where ice did not even remove the weathered material. Finally, he expresses doubts on theoretical grounds of the capacity of continental glaciers to erode deeply. The objections of other geologists are adequately covered by these same points.

ALTERNATE HYPOTHESIS

That glacial deposition blocking the outlet of preglacial depressions is the principal cause of the Lakes has been suggested. Spencer[5] believed that the basins were cut below present sea level by streams as a result of uplift prior to the glacial period. Attention has also been called by Thwaites and others to the warping in the Great Lakes region which might suggest a diastrophic origin. Other deep basins, such as the Rift Valley lakes of Africa, the large lakes of Asia, and the basins of Nevada and Utah have been caused by diastrophism.

TESTS OF THE HYPOTHESES

Though it is recognized that in all probability several factors have contributed to the development of the Great Lakes basins, the question arises whether some one of them has not been of major importance. Tests may be applied which should make a decision on this point possible.

DRIFT-OBSTRUCTED PREGLACIAL VALLEYS

In the first place, if the basins are largely drift-obstructed valleys, cut originally by river erosion, the bottoms of the basins should be higher than the rock floors of the seaward extension of these old valleys. Also, the basins should show cross-sections of a character suggestive of river erosion and in keeping with the relation of the valleys to the drainage divide.

These expectations are not fulfilled. It is well known that all the Great Lakes except Lake Erie extend below sea level (for maximum depths see fig. 1), and their rock bottoms may be at a much greater depth than shown by the soundings because the retreat of the ice may have left considerable drift coverings in these basins. Thwaites notes that "well records fail to show any wide preglacial valleys leading out of the basins of the Great Lakes," and "* * * the rock bottoms of the Mississippi and other preglacial valleys are much

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[5] Op. cit., p. 94.

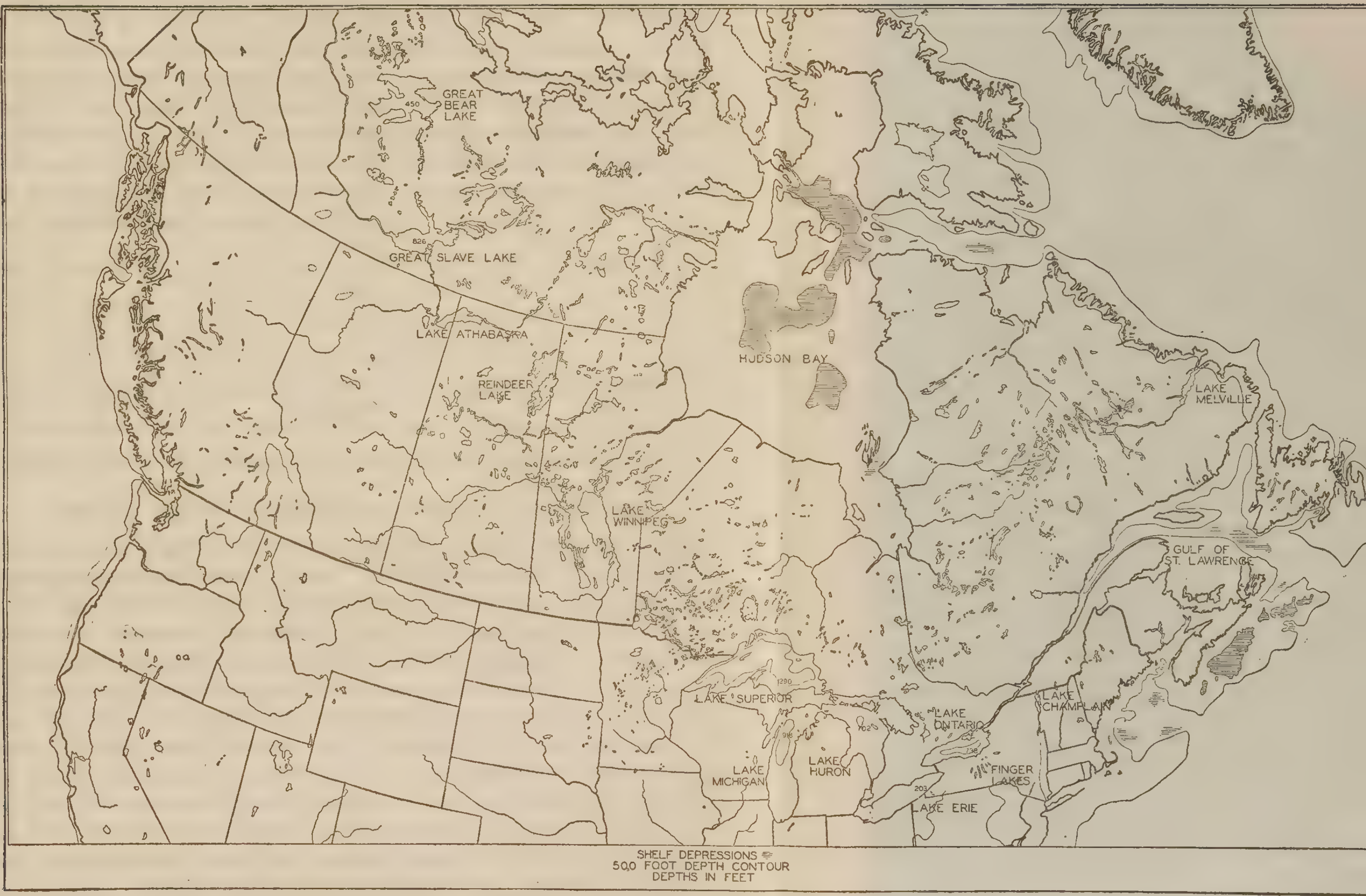
GREAT BEAR LAKE
450
826
GREAT SLAVE LAKE
LAKE ATHABASKA
REINDEER LAKE
HUDSON BAY
LAKE MELVILLE
LAKE WINNIPEG
GULF OF ST. LAWRENCE
1290
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE CHAMPLAIN
FINGER LAKES
203
LAKE ERIE
SHELF DEPRESSIONS
500 FOOT DEPTH CONTOUR
DEPTHS IN FEET

FIGURE 1.—Showing the basins associated with glaciation in North America. Depths are in feet. The principal basins on the continental shelves are shaded.

higher than the bottoms of the Great Lakes."[6] In order to assume some gradient toward the Mississippi, which was probably the preglacial outlet of the Great Lakes drainage basin, the bottoms of the preglacial valleys must have been almost as high as the present surface of the Great Lakes. Furthermore, the area in question, being so centrally located, must have been close to the drainage divide. It is hard to conceive of river valleys in such a location with floors as wide as those of the Great Lakes basins (fig. 2). Nor do the sides of the basins have the typical sinuous outlines of river valleys. Under the circumstances it seems unwise to attribute the present deep basins of the Lakes to preglacial river erosion although the probability that small river-valley depressions existed along the lines of the Great Lakes must be recognized. As a corollary, glacial deposition must be relegated to the unimportant role of helping to limit the size of basins formed in other ways.

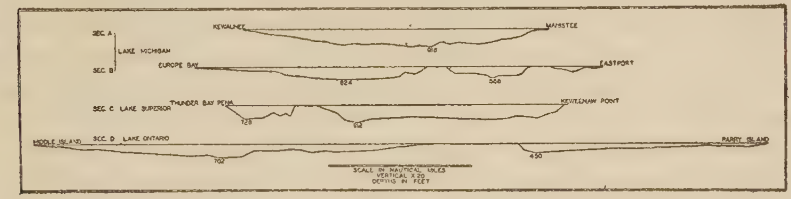

FIGURE 2.—Cross-sections of the Great Lakes. Note the relatively steep sides and broad base.

SIMILAR BASINS IN GLACIATED REGIONS IN GENERAL

A second test may be made of the relative merits of the hypotheses of glacial erosion and diastrophism. If the basins were due to glaciation, similar basins might be found widespread over the glaciated territories of the world; whereas, if they are diastrophic, such a wide distribution in glaciated regions would be most unlikely. In considering this criterion three things must be borne in mind—first, that some of the basins do not appear as lakes because they are completely submerged by the ocean; second, that the basins in areas glaciated in early epochs would have been filled to a considerable extent; and, third, that the greatest gouging action of the ice would be expected around or close to the margins of ice sheets, so that the absence of basins in the interior would not be significant. With these points in mind we may proceed to an examination of the principal glaciated territories.

A map of North America (fig. 1) shows a series of large lakes occupying basins in the soft rocks on the south and west borders of the Canadian shield, and bathymetric maps show that a lowering of sea level would leave similar lake basins in the gulfs and bays southeast and north of the shield. The Great Lakes basins are neither the largest nor the deepest of these features. The Finger Lakes of New York State and Lake Champlain are smaller than, but almost as deep as, the Great Lakes. The Gulf of St. Lawrence is comparable to the Great Lakes and contains large, deep, rimmed depressions.[7] Along the coast of Labrador a few inlets, notably Lake Melville, are also comparable, but in general the inlets or fiords are too small to warrant consideration.

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[6] Op. cit. (1st ed.), p. 43.

North of Canada the series of straits and gulfs among the islands have been charted only very crudely, and soundings are scarce. Such information as is available, however, suggests that these bodies of water are similar to the Gulf of St. Lawrence and probably contain basins of a depth and size quite comparable to the Great Lakes. Hudson Bay has been sounded sufficiently to show that it has basins within it which compare in dimensions with the Great Lakes. Great Bear Lake, Great Slave Lake, Lake Athabasca, Reindeer Lake, and Lake Winnipeg are almost as large as the Great Lakes. Their depths are not well known, but soundings in Great Slave Lake show a maximum of 826 feet and in Great Bear Lake of 450 feet [8]—depths not unlike those of the Great Lakes. On the other hand, Lake Winnipeg does not have depths much in excess of 60 feet so far as is known.

In the European glaciated area (fig. 3) there are various large lakes, and the seas and gulfs contain many basin depressions. The Skager Rack, south of Norway, has a deep, rimmed basin.[9] The Baltic Sea, the Gulf of Bothnia, and the Gulf of Finland all contain sizable depressions. Farther east in the Soviet Union are Lake Ladoga and Lake Onega. The White Sea contains a deep basin, and the continental shelf in the Barents Sea contains a series of deep, rimmed depressions.

All these examples of large basins in glaciated regions of relatively low relief show that the Great Lakes are features characteristic of continental glaciation. The areas immediately outside the glaciated regions, together with much of the area of marginal glaciated territory, where the glaciers were thin and of short duration, have few basins both on the lands and on the continental shelves. Accordingly, it appears that the Great Lakes are in some way related to glaciation.

DIASTROPHISM IN GLACIATED TERRITORY

The possibility must be considered that the abundance of basins in the glaciated territory simply means that this territory has also be very active diastrophically. Tests will be applied to see whether th

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[7] Shepard, F. P., The St. Lawrence (Cabot Strait) submarine trough. Bull. Geol. Soc. Amer., vol. 42, pp. 853–64, 1931; see also fig. 6, p. 860.

[8] From information kindly supplied by F. Anderson, hydrographer, Canadian Hydrographic Service.

[9] Shepard, F. P., Glacial troughs of the continental shelves. Journ. Geol., vol. 39, fig. 9, p. 352, 1931.

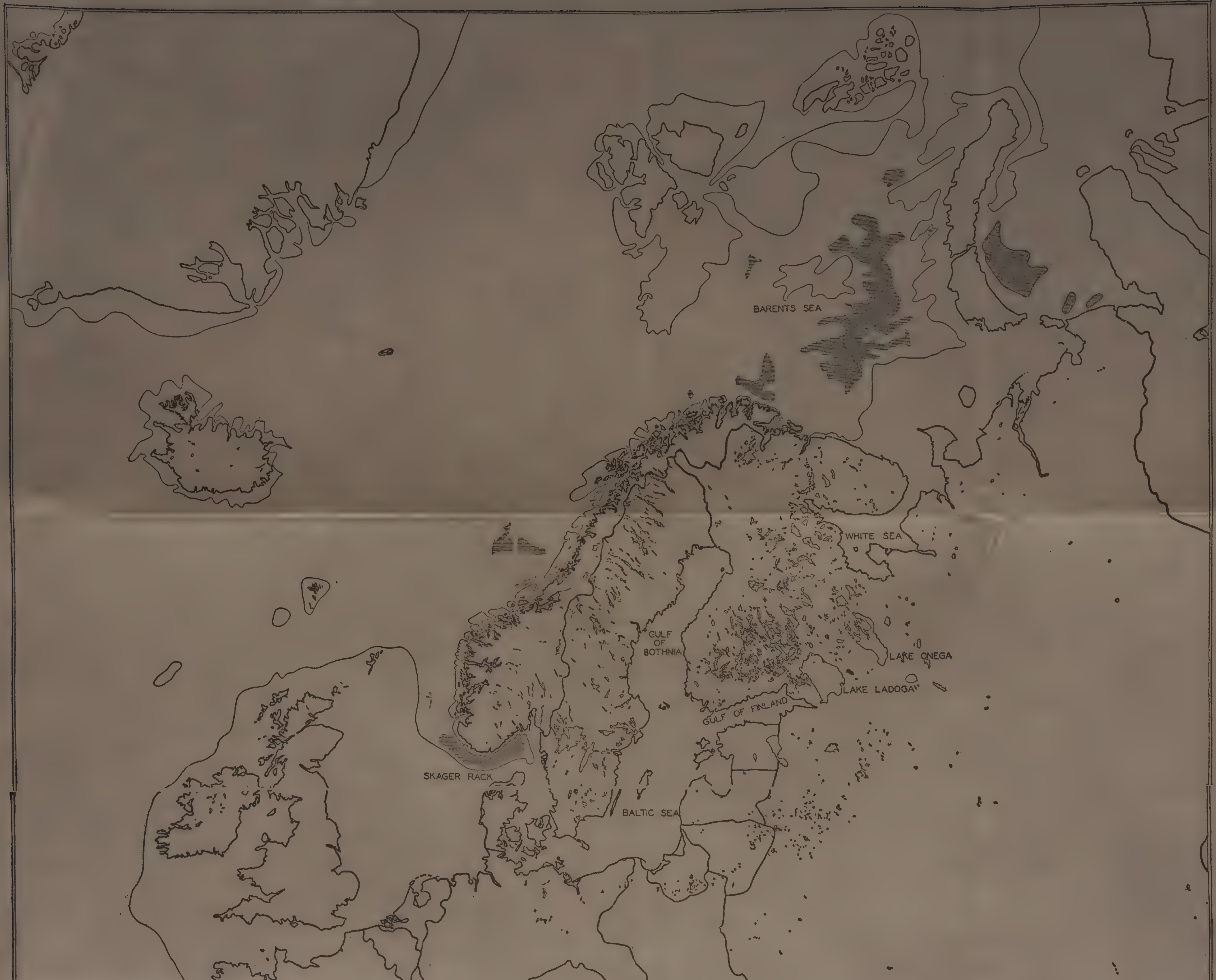
BARENTS SEA
WHITE SEA
GULF OF BOTHNIA
LAKE ONEGA
LAKE LADOGA
GULF OF FINLAND
SKAGER RACK
BALTIC SEA
SHELF DEPRESSIONS
500 FOOT DEPTH CONTOUR

FIGURE 3.—Showing the basins associated with glaciation in northern Europe. Basins on the continental shelves are shaded.

is the case. First, let us consider the earthquake distribution in relation to glacial territory. If we place the great seismic belts and the glaciated territory on the same world-map, we find that the two hardly coincide at all (fig. 4). Further consideration shows that both the Scandinavian center in Europe and the Labradorian and Keewatin centers in America are related closely to ancient shields where stability has long been developed. Nor are there notable fault scarps and fault troughs developed in these regions.

Now, if we consider the other areas of the world which contain large basins, we find a very different picture. These areas are found within earthquake belts in practically every case. The areas contain a maze of fault scarps and all other indications of having been active diastrophically in recent times.

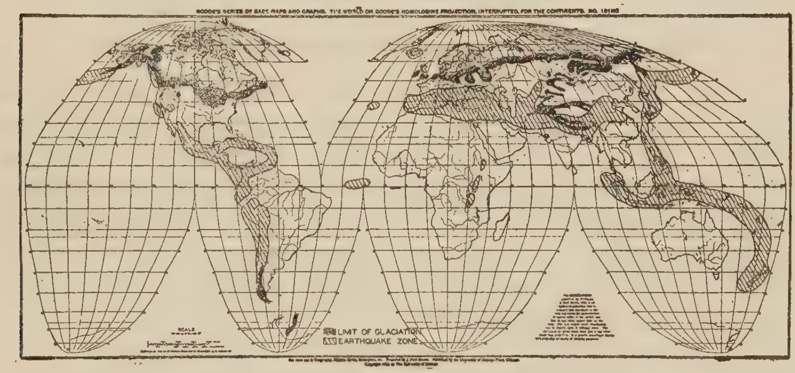
GOODE'S SERIES OF BASE MAPS AND GRAPHS. THE WORLD ON GOODE'S HOMOLOSINE PROJECTION, INTERRUPTED, FOR THE CONTINENTS. NO. 101HC
SCALE
▨ LIMIT OF GLACIATION
▧ EARTHQUAKE ZONE

FIGURE 4.—Showing the lack of relation between earthquake belts and glaciated territory.

The argument that there has been warping in glaciated territory in postglacial times requires some consideration since this may represent the cause of the basins. It is generally agreed, however, that this warping is the result of readjustment of the earth's crust following the release of the load of the continental glaciers. The compilation of the data by Gutenberg [10] shows that, so far as the Great Lakes area is concerned, there is a progressive rise from the southern boundary of the lakes to the north. The principal effect of such a tilt would be to decrease the size of the basins, and it certainly should not be considered as an important factor in their production.

MOVEMENT OF THE ICE

The various opponents of the idea that ice excavation is important have made much of the presence of deep basins transverse to the general motion of ice. This is true of many of the fiords along the various glaciated coasts of the world. It does not, however, disprove the glacial-excavation hypothesis. It is well known that in areas of continental glaciation numerous glacial striations cross the general direction of ice flow. Also, as has been pointed out by Bretz,[11] the present continental glacier of Greenland has a concentrated flow along the fiords which are buried beneath the ice of the interior. This observation helps explain why there is such clear evidence of excavation along certain valleys in formerly glaciated regions whereas the uplands between the same valleys were not subject to much glacial erosion.

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[10] Gutenberg, B., Tilting due to glacial melting. Journ. Geol., vol. 41, p. 458, fig. 3, 1933.

That the ice did move down the Great Lakes basins is clearly indicated. The map compiled by Leverett [12] shows the various lobes of ice which occupied each of the basins. These lobes have been demonstrated by the glacial striations and by the morainic belts which surround the outer termini of the Great Lakes basins.

COMPARISON WITH FIORDS AND OTHER GLACIAL FEATURES

It is quite generally conceded that fiords are due largely to glacial erosion. Also, the large lakes of Switzerland and other glaciated mountain ranges are certainly glacial excavations.[13] The writer called attention to the complete gradation which exists between fiords and submarine troughs out on the open continental shelves off glaciated coasts.[14] The Great Lakes, likewise, can be shown to be related to the mountain lakes of Switzerland with all gradations between the two. All four of these features have many points in common. Thus, while the Great Lakes are not strictly U-shaped, their transverse profiles are trough-shaped with relatively steep walls on either side (fig. 2). Also, the sides of the lakes are comparatively straight as are the sides of many glacial valleys in the mountains and the fiords of glaciated coasts. The unconnected depressions which characterize Lake Superior (fig. 5) have their counterpart in most fiords and in many large mountain lakes. The rocky islands within Lake Superior, which were cited by Thwaites as an argument against ice erosion, are matched by the rocky islands of most fiords and are found also in some of the Swiss lakes.

In 1870 Andrews [15] called attention to certain subaqueous terraces along the margin of Lake Michigan which he thought extended to depths of 60 feet. Johnson [16] subsequently examined the evidence

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[11] Bretz, J. H., The fiord region of East Greenland. Geog. Soc. Spec. Publ. 18, p. 239, 1935.

[12] Leverett, F., and Taylor, F. B., The Pleistocene of Indiana and Michigan. U. S. Geol. Surv. Monogr. 53, pl. 5, opp. p. 62.

[13] The attempts which have been made to explain fiords and mountain lakes as diastrophic are not characterized by the clear reasoning which scientific arguments should have. This point is well developed by D. W. Johnson, The origin of fiords. Science, n. s., vol. 41, pp. 537–43, 1916.

[14] Shepard, F. P., Glacial trough of the continental shelves. Journ. Geol., vol. 39, pp. 347–57, 1931.

[15] Andrews, Edmund, The North American lakes considered as chronometers of post glacial time. Chicago Acad. Sci. Trans., vol. 2, pp. 1–23, 1870.

[16] Johnson, D. W., New England-Acadian shoreline, pp. 405–15, 428, John Wiley & Sons, New York, 1925.

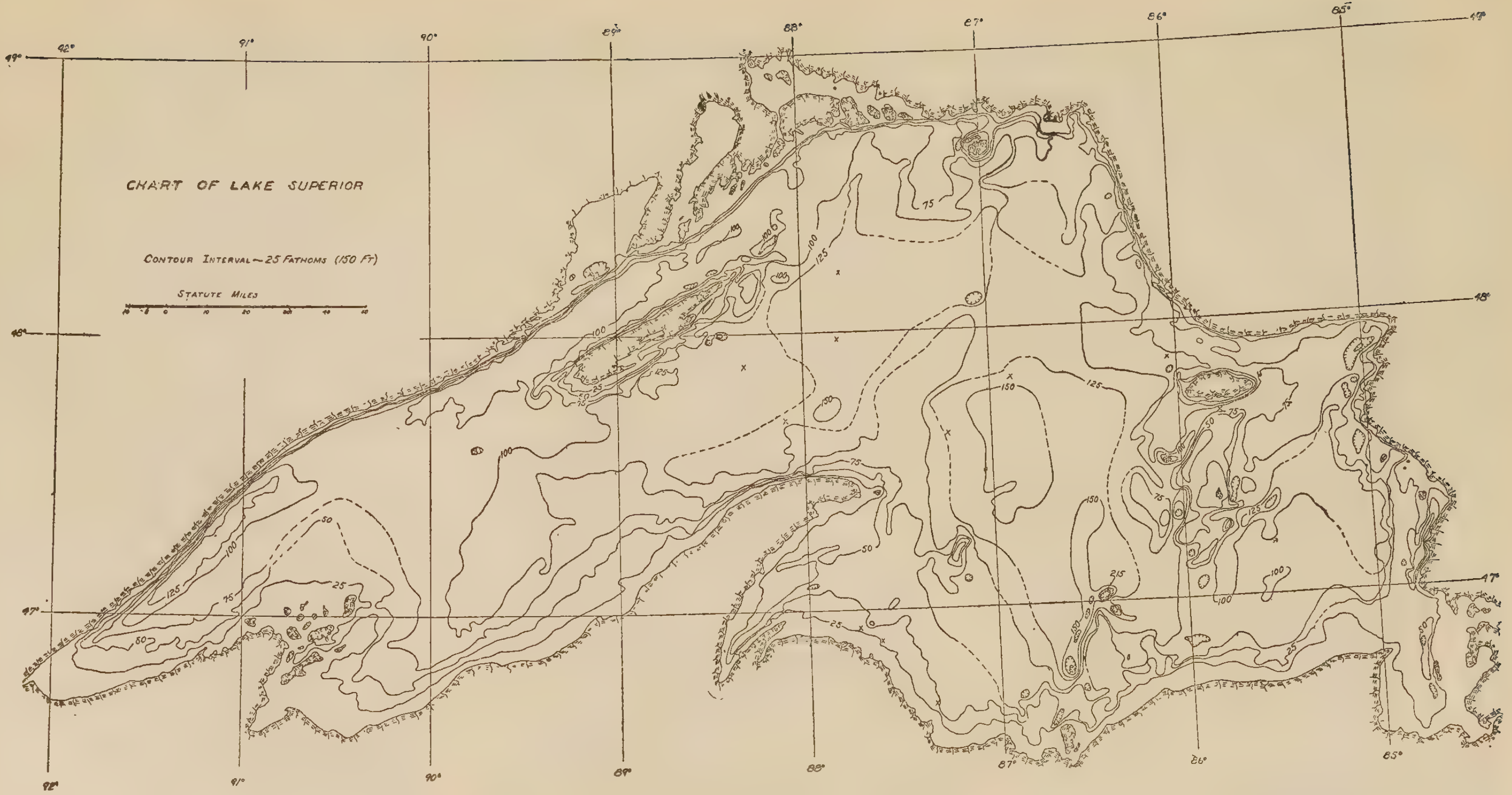
CHART OF LAKE SUPERIOR
CONTOUR INTERVAL — 25 FATHOMS (150 FT)
STATUTE MILES
10 5 0 10 20 30 40 50
49°
48°
47°
92°
91°
90°
89°
88°
87°
86°
85°
25
50
75
100
125
150
215

FIGURE 5.—Contour map of Lake Superior. Depths in fathoms.

for these terraces and concluded with good reason that the soundings did not permit any such generalization as Andrews had made. He suggested that the terraces and valleys on the lake floor at some places were submerged land features. However, some of these valleys cited have been shown by the recent surveys to contain deep, rimmed depressions so that they can hardly be ascribed to river erosion, and near them are similar features more than 600 feet deep (fig. 6, lower left corner). Is it not more reasonable to assume that these features were produced by glacial erosion, especially as some of the submerged valleys have distinct U-shaped transverse profiles?

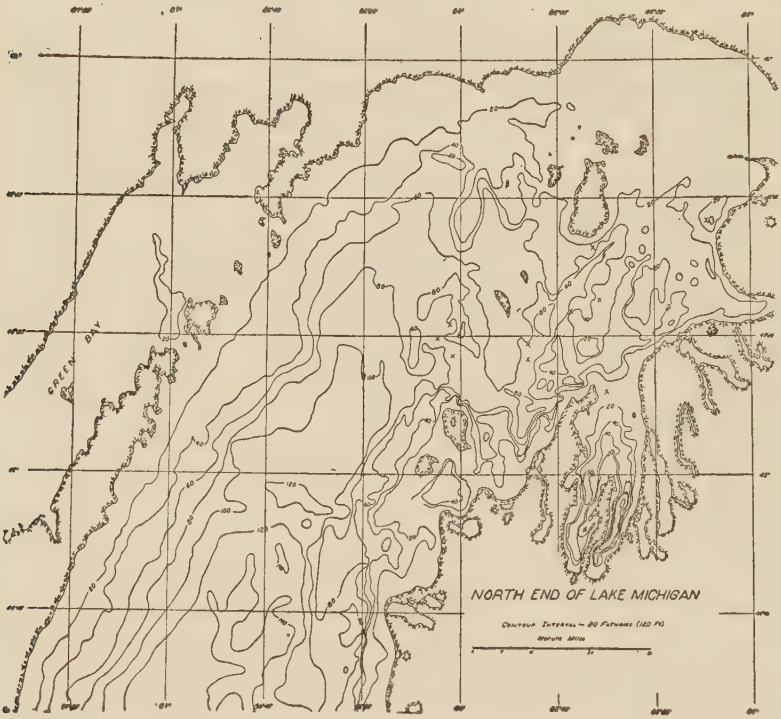
GREEN BAY
NORTH END OF LAKE MICHIGAN
Contour Interval – 20 Fathoms (120 Ft)
Statute Miles

Figure 6.—Contour map of the northern portion of Lake Michigan.

The irregular topography of the lake bottoms, especially that of Lake Superior, suggests that it has not been greatly modified by postglacial deposition. The "rock bottom"[17] reported in surveys from various parts of the lake floors and glacial till reported from Lake Michigan[18] and from Lake Erie[19] corroborate this conclusion.

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[17] These may be largely boulders rather than bedrock.

[18] Hough, J. L., The bottom deposits of southern Lake Michigan. Journ. Sed. Pet., vol. 5, pp. 57–80, 1935.

[19] Kindle, E. M., personal communication.

THICKNESS OF GLACIAL DRIFT

One of the most convincing arguments favorable to glacial excavation of the Great Lakes is the enormous quantity of glacial drift found south of these basins. Despite postglacial erosion and the fact that a large percentage of the debris was carried beyond the glacial margins by glacial outwash, the surfaces are, nevertheless, covered with drift which is commonly a hundred or even several hundred feet in thickness. Furthermore, the nature of the drift is such as to suggest derivation from adjacent lake basins as, for example, the clayey till of Illinois which was presumably derived from the shales of the Lake Michigan basin. The freshness of a large part of the drift, particularly the younger sheets, shows conclusively that the glaciers were digging into solid rock rather than just removing the mantle rock from old weathered surfaces.

CONCLUSIONS

The various tests which have been applied to the hypotheses of origin of the Great Lakes appear to give overwhelming weight to glacial erosion as the principal cause. Possibly such a conclusion is not justified, but more significant evidence should be given before assuming alternative modes of origin. If it is true that the Great Lakes, the various other large basins in glaciated territory, and the deep arms of the ocean along glaciated coasts are all largely the product of glacial erosion, one is led to wonder whether the glaciers were not much thicker than commonly assumed. An average thickness of 4 miles or more for the continental ice masses have been suggested by the writer as a cause of great lowering of sea level to permit the cutting of submarine canyons. If the ice was that thick, the cutting of large basins might have been greatly intensified.

THE BIOGRAPHY OF AN ANCIENT AMERICAN LAKE[1]

By Wilmot H. Bradley
Geologist, U. S. Geological Survey

[With 4 plates]

As in olden times, when Kublai Khan held absolute rule over a vast domain and progressively amassed great wealth by reason of the tribute that flowed in from outlying provinces, so in a far remoter epoch, long antedating human history, a great lake held sway over a vast area in the Rocky Mountain region and gradually accumulated in tremendous volume a potential natural resource derived from the sun's unfailing supply of energy and from the mineral burden that flowed in from adjoining lands through its tributaries.

So remote was this epoch that could we go back to it in time we would be compelled to gage our progress by the slow evolution of animal life and the gradually changing expression of the earth's face. We would have to go backward with undreamed-of speed past a pageant of animals that inherited the earth in slow succession as evolution molded them. So short is man's history that it would flit by too quickly to be perceived. Passing backward in a brief moment through the silent ice age, we would see man's primitive ancestors, together with giant sloths, giant bears and beavers, and the woolly mammoth. Farther back we would meet small elephants and, on the plains, bands of horses, wild asses, and camels. Farther back in time's flight we would find their smaller and ever smaller precursors. Suddenly would appear the hippopotamuslike titanotheres and a host of other strange creatures, each leading a succession of smaller and less specialized ancestors. Finally we would come to the time of the diminutive four-toed horses, which dwelt in the forests and grassy parks of that epoch of long ago when the ancient lake came into its regency.

This great lake, known as "Lake Uinta," occupied a long, shallow basin or downwarp of the earth's crust about a hundred miles southeast of Utah's present Great Salt Lake. The record it left is preserved in the form of an immense body of nearly flat-lying beds or layers of fine-grained rock similar to lithographic stone. This great body of rock is as long as Vermont but considerably wider, and in places it is almost a mile thick. Deep canyons and wide valleys are now cut through it in all directions, so that the whole record is accessible.

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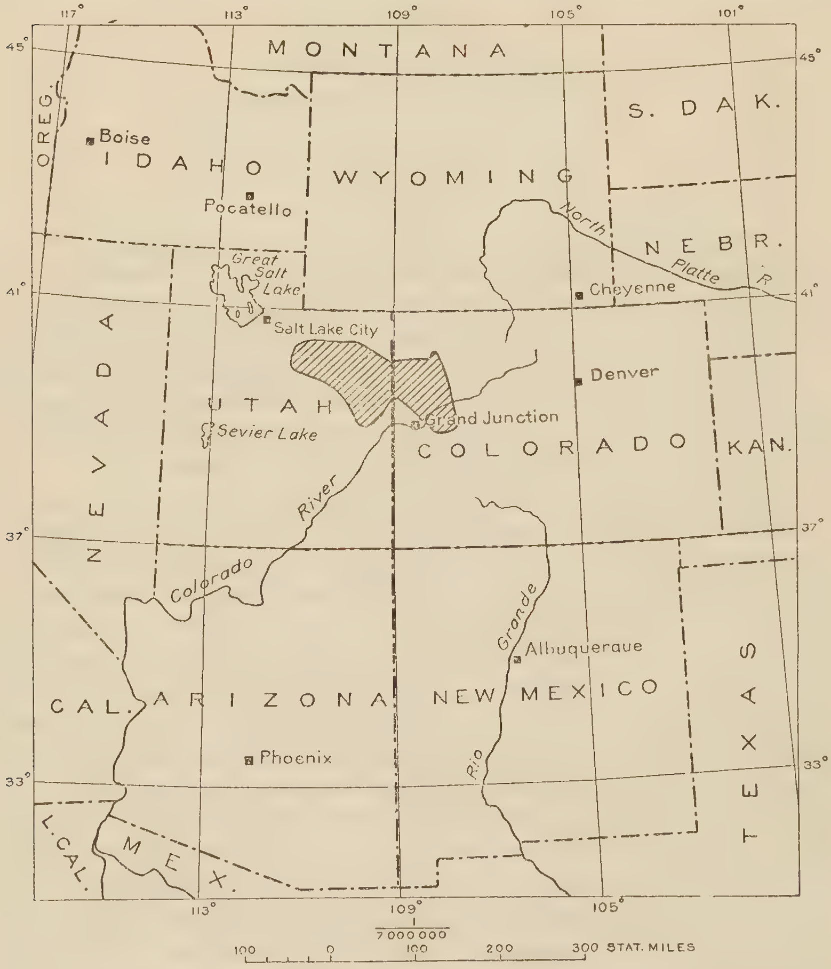
[1] Published by permission of the Director, U. S. Geological Survey. Reprinted by permission from the Scientific Monthly, vol. 42, pp. 421–430, May 1936.


117°
113°
109°
105°
101°
45°
41°
37°
33°
MONTANA
OREG.
Boise
IDAHO
Pocatello
WYOMING
S. DAK.
North Platte R.
NEBR.
Great Salt Lake
Cheyenne
Salt Lake City
Denver
NEVADA
UTAH
Sevier Lake
Grand Junction
COLORADO
KAN.
Colorado River
Rio Grande
Albuquerque
CAL.
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NEW MEXICO
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FIGURE 1.—Index map showing the location and approximate extent of the ancient Lake Uinta.

The thin layers thus exposed bear a remarkably close resemblance to the leaves of a book. Indeed, it is more than a superficial resemblance for the layers are in fact pages upon which are impressed symbols that portray events of that age so long past.

Modern books are so familiar that we take little thought of their construction and have no difficulty in reading their meaning. But when the earliest written records of man were found they could be read only after learning how the symbols were formed and what relation each bore to modern language. So it is with the record left by the ancient Lake Uinta. Geologists in the seventies of the last century pried apart the stony pages and found that they contained a story about an ancient lake. But the story could be read no faster than the science of geology grew and provided the keys for interpreting the symbols. Moreover, the reading was slow because fragments of the record came to light only piecemeal as exploring geologists penetrated more and more deeply into those parts of the arid West away from established routes of travel. And finally, long passages in the text remained obscure until the study of modern lakes revealed what was taking place in them, for the characteristics of an ancient lake can be understood only by analogy with the lakes of today. Thus only recently, as more and more parts of the story have been assembled and integrated into an ordered sequence, has it been possible to learn how complex and varied is the history of Lake Uinta. That history includes a wealth of information, not only about the plant and animal societies that dwelt in the lake itself and on the adjacent land, but also about the ways in which they changed to meet a gradually changing environment. It tells how for thousands of years the lake kept a sort of calendar, by depositing each year a thin layer of peculiar sediment that was sharply marked off from the layers formed the year before and the year after. Though these annual layers do not continue through the whole record it has been possible from them to estimate that Lake Uinta was in existence for millions of years. The history is more than a recital of elapsed years, however, for it tells both of major catastrophes and of such trivial incidents as the migration along the water's edge of a swarm of small, swollen-headed larvae which, had fate been less harsh, would one day have split their skins and emerged as adult gnats. From this emergence, however, they were prevented by a drop in the lake level, which left them to perish and dry in the sun until the water rose again and deposited on their remains a shroud which it fashioned out of minute interlocking mineral particles.

I

In the beginning the site of Lake Uinta was a broad, nearly level alluvial plain—a sort of huge amphitheater, bordered on three sides by mountains but open to the south. Streams from the mountains wound listlessly across the plain and rested in the grassy marshes. But this landscape was destined to change, for, beneath the plain, the stony shell of the earth was beginning with subtle slowness to warp downward. Thereafter the streams spread broadly over the meadows, changing them to lakes. At first there were two large lakes, but as the downwarping continued these soon expanded and coalesced into a single sheet of water as long as Lake Ontario but much wider. Thus Lake Uinta came into being.

Up from the north shore rose the great swelling bulk of the Uinta Range, its flanks green with forest. This forest may or may not have its counterpart living anywhere in the world of today; nevertheless, it must have been much like the forest that would develop on the southern slope of a high mountain on the present Gulf coast of the United States, could we but conjure up a mountain in that region. Just as such a forest would have different kinds of plants growing at successively higher levels, so it is probable that the forest which clad the Uinta Range in that ancient epoch was also zoned according to the altitude. Fossil leaves, flowers, seeds, and even pollen grains collected from the bottom deposits of the ancient Lake Uinta enable us to reconstruct the probable floral zones of a landscape that existed during the Eocene epoch more than 30 million years ago.

At the water's edge grew bur reeds, rushes, water milfoils, and the familiar purple-spiked pickerel weed. But upon the shore and the wide flats adjacent to it grew trees whose nearest relatives—japonica, figs, and a variety of aromatic shrubs and trees—now live in the warm-temperate parts of the earth. Vines, very similar to if not identical with our modern grape, grew along with gourds, delicate climbing ferns, and the less inviting cat briers. Where the bottom lands were sandy, palm leaves cast their slatted shadows on the ground.

If we could have gone back through the swampy bottoms we would have found, among others, mimosa trees and trees related to the cinnamon growing with a large variety of ferns and evergreen shrubs. Pushing farther into the drier foothills, we would have passed through woods of oak, maple, hickory, and gum—woods nearly indistinguishable from the present hardwood forests of temperate North America. Higher up, pine and hemlock supplanted these familiar hardwood species, and in the highest parts of the range forests of spruce and fir predominated. That the evergreen forests were remote from the ancient lake is attested by the fact that only one seed and the tip of one twig of these species have ever been discovered in the lake deposits, though leaves of lower-zone types are found there by the hundreds. Nevertheless, forests of pine and spruce flourished; their former presence is manifested by an abundance in the lake deposits of their odd pollen grains, each of which is fitted with two bulging air sacks that aided it to float many miles from the parent tree.

The insects, too, resembled rather closely those now living. Caddice-flies, whose larvae build about their bodies little masonry houses of sand grains or well-joined "log" houses of tiny twigs, frequented the shallow water at the lake's margin, together with the more familiar dragon flies. The wobbly-legged crane fly was there with his diminutive cousins, the midges. Beetles, crickets, and the homely grasshopper were common, but if there were butterflies and moths they have left no trace. Animals coming to the lake shore must have found it a disagreeable experience, for there they met clouds of mosquitoes, black flies and gnats, and larger flies that bit savagely. Spiders and the lowly cockroach have been found, and even one mite, which, incidentally, has the distinction of being the most ancient mite in North America—America's oldest louse, if you will.

Crocodiles shared with various river turtles the sluggish parts of the streams near the lake. Land tortoises, rivaling in size the famous ones from the Galapagos Islands, plodded through the sandy lowlands. Snakes, too, there were; indeed, the most nearly perfect fossil snake ever found in the Western Hemisphere came from these lake beds. Water birds, like the loons, sandpipers, and rails, must have been numerous, for impressions of feathers are common on the slabs of rock that were once mud flats bordering the lake. Of the birds themselves we know next to nothing—fossil birds are rarae aves indeed. Oddly enough, however, the one remarkably fine fossil bird that has been found in these lake beds was a native of the uplands similar to our ruffed grouse.

Despite the modern aspect of the forest that encircled ancient Lake Uinta, the warm-blooded mammals that lived in it were decidedly strange. Particularly striking was the ancestor of the modern horse, for it stood no higher at the withers than an Airedale pup. Its back arched somewhat, and instead of one hoof to the foot it had four slender hoofs on each front foot and three on each hind foot. These hoofs, however, bore less of the animal's weight than did a pad at the base of the toes. The teeth of this primitive horse, unlike those of its modern descendant, were adapted to feeding upon leaves and soft, lush plants, for the West at that time was green with forest and meadow. Only through the following millions of years did it become the semiarid region that we know today.

A fisherman peering down through the clear water to see what manner of fish there were among the pond weeds would not have been disappointed. Perch and other fresh-water fish inhabited the weedy bays, but they were greatly outnumbered by varieties of herring. Today, most herring live in the sea, though a few go up rivers to spawn and a few others live in rivers. Thirty million years ago more varieties apparently went into fresh water to spawn, for those found as fossils are of two sizes—fry that had not long left the spawning ground and adults that had presumably returned from the sea to spawn. Least to be expected so far from their usual marine environment were the large sting rays. The occurrence of so many forms that spent part of their lives in marine water implies that for a long time a perennial river ran from Lake Uinta to the sea, even though the lake was probably 600 or 800 miles inland. So great a distance from the sea would not have precluded intermigration, for salmon are known to travel more than 2,000 miles up the Yukon to spawn.

II

By the time Lake Uinta had become thus well stocked with fish it was a mature lake, for it had already been in existence more than a million years. Now as lakes grow old they, like men, acquire stores of worldly goods. So it was with Lake Uinta; as it advanced in age its waters became increasingly rich in foodstuffs. And, like a benevolent monarch, the lake gave all this increasing wealth for the good of its subjects—the varied and extensive aquatic population.

The life of a populous lake is a complex society, the members of which are interdependent. Most elemental are the microscopic plants and animals that float freely in the surface waters and derive their nourishment and energy directly from the sunlight and the dissolved salts. Upon the abundance of these minute creatures depends the very existence of other life in the community, for they are the ultimate source of food. Successively larger animals—the fairy shrimp, the water flea, and the highly mechanized wheel animalcules—feed upon them and in turn are fed upon by small fish.

At this mature stage of Lake Uinta these tiny specks of life found themselves in a congenial environment, where food abounded and the temperature was most agreeable. They flourished in the midst of plenty and, late in the summer, when the water had been thoroughly warmed, literally took possession of the lake. Their numbers increased at an astounding rate; they clouded the water, then turned it a fulvous green, and finally covered it with a green scum, which the wind parted into lanes where the water might ripple again and reflect the blue of the sky. From beneath this surface stratum, filled with life, those organisms that had grown weary of the struggle for existence floated gently downward and sought rest in the quiet depths. So vast was the number of these weary motes that, despite their microscopic size, they bulked large in the total volume of sediment that reached the lake bottom. Indeed, these late summer epidemics gave rise each year to a distinct dark layer of organic substance. It was partly by means of these organic layers that the ancient lake recorded the passing of the years. But there would have been nothing to mark one layer off from another formed the following year or the year before, if it had not been for a different kind of sediment, which accumulated more or less continuously throughout the year.

Streams brought to the lake not only fine mineral particles in suspension but also the elements of other minerals in solution. Those particles that rode in on the streams' turbulence found nothing buoyant in the quiet lake and hence settled placidly to the bottom. But the elements in solution were dispersed through the whole water body and, under the influence of the sun's warmth and the breathing of minute plants, combined with other elements to form tiny white flecks of mineral—particles of lime carbonate. These settled to the bottom as a gentle rain the year around, but most plentifully in the early summer, and formed a light-colored granular deposit that separated the dark organic layers from one another. Thus, because the dark organic layers were formed at a certain time each year and because the organic matter was then abundant enough to mask out the light-colored particles, each dark layer told off the passage of a year.

The ancient lake continued to serve as an annual calendar in this manner for thousands and thousands of years, interrupted only at long intervals by a fall of volcanic ash or by a storm of extraordinary vigor that stirred even the deep bottoms. The layered deposit was ultimately changed into rock, but the thin velvety dark bands still stand out sharply from the light-buff matrix. These layers are very thin—about 150 of them to the inch. This means that it required about 1,800 years for enough material to accumulate on the bottom of the ancient lake to make a slab of rock 1 foot thick. As might be expected, the varieties of rock consisting of the coarser mineral particles were built up somewhat more rapidly than this, and the finer-grained rocks, those consisting predominantly of organic substance, much more slowly. The measured rates of accumulation range from 250 to 8,200 years to the foot. By applying the rate at which each kind of sediment accumulated to the quantity of that kind of sediment throughout the body of material deposited in Lake Uinta it has been possible to estimate that the lake was in existence approximately 7,500,000 years. In this long period evolution had time to remold some of the more impressionable races of animals living in the neighborhood. For instance, ancestors of the horse family that lived at about the time Lake Uinta vanished were larger and had notably better grinding teeth than their forebears that lived just before the lake came into existence; moreover, in that interval evolution also altered somewhat the design of their toes.

In the record which the ancient lake kept year by year, we find the suggestion that the lake's volume and temperature varied in sympathy with the changing face of the sun—that is, with the number of sunspots. Admittedly this correlation is no more than a suggestion, yet there is a fairly sound theoretical basis for believing it to be real. Foregoing all effort to explain the steps, we may present the argument in its briefest form somewhat as follows: Sunspots are most numerous at intervals of about every 11 years, and these cycles signify changes in the amount of radiant energy that the sun emits. It has been observed that the levels of lakes which lose most of their water by evaporation and relatively little by overflow show a much closer relation to the number of sunspots than to rainfall; in general, the fewer the sunspots the lower the lake level. Lake Uinta at this stage had no outlet and lost much of its water by evaporation—therefore it must have had such a cyclic fluctuation of level. Next, in general the temperature of lake water rises as the lake goes down, and the higher temperature favors the growth of the minute surface-dwelling organisms and also the precipitation of particles of lime carbonate. This gives a further check on the ancient conditions, for in the deposits of Lake Uinta the layers of organic substance and lime carbonate differ in thickness from year to year and show maxima at intervals that average about 11 years. Similar cyclic variations have been observed in the thickness of annual layers formed in modern lakes. It is also a suggestive fact that the annual rings of trees that grew around Lake Uinta show even better the same 11-year cycle, just like the growth rings in modern trees.

Much longer cycles, whose average length was about 21,000 years, are also recorded in the deposits of Lake Uinta. By a somewhat more involved line of reasoning we are led to think that these observed variations in the lake deposits may be correlated with the resultant of two astronomic cycles—the change in eccentricity of the earth's orbit and the precession of the equinoxes. It remains to be seen whether these and other comparable cyclic variations in the climate of the past can ever be used by meteorologists in their researches into secular changes of climate.

III

Lake Uinta and the surrounding countryside did not always present a picture of smiling beauty, with forests and green meadows. Instead during the later half of its existence death and starvation laid heavy hands upon the community. From time to time pallid blankets of volcanic ash descended upon it and snuffed out the life. Animals and plants alike were smothered, and the streams were clogged with the harsh mud. Gradually, as rains washed off the slopes, the forest renewed its growth and animals again sought its shelter. But it was to no purpose, for again and yet again at long intervals the volcanoes in the neighboring mountain chains belched forth devastating clouds of pumiceous ash.

As if these recurrent disasters were not enough, the rains came less frequently: the very life-giving source of moisture began gradually but surely to dry up. Under the pitiless summer sun the more lush plants withered and finally gave up, weary of waiting for the rain. Animals wandered away in search of water.

The lake, too, suffered. For a long time it overflowed only during the cooler rainy season, but as the years passed the thirsty air drew more and more greedily from its surface until finally even at the highest stage the water could not reach the outlet. Thereafter Lake Uinta fluctuated greatly in size with the changing seasons and with every change in the weather, for a lake that has no outlet and loses by evaporation as much as it receives is extremely responsive to slight variations in atmospheric conditions. As the water level varied, it alternately flooded and left bare wide expanses of mud. Upon these wet mud flats scores of fish were stranded and flopped until they stiffened in the sun. Insects, dazzled by the reflected glare from the wet mud, alighted only to have their wings and feet caught in the drying surface film. When the water level rose again, perhaps only by reason of an onshore wind that pushed a thin sheet of water far up over the nearly level bottom, both fish and insects were sealed beneath a new layer of mud and so were preserved and made part of the enduring record.

As the lake retreated from its former shores it concentrated into smaller compass the community of living things that had formerly occupied a more spacious domain. The water was proportionately enriched in dissolved foodstuffs, and the density of the population increased manyfold. But conditions gradually became so congested that many forms were unable to survive. Their place, however, was immediately taken by a host of other organisms better fitted to endure the foul environment. Indeed, after thousands of years of slow dwindling Lake Uinta finally became, at its lowest ebb, a truly horrid thing—a great festering abscess breathing its stench into the shimmering summer heat. The water became bitter with salt, and the decaying organic material in the shallowest places seethed with fly maggots as they fed upon it. How abundant those maggots were is plainly told by the fact that layer after layer of them was buried, and today their overlapping flattened bodies make continuous paper-like layers in the thinly laminated rock that was once the lake-bottom mud.

This lowest stage in the history of Lake Uinta indicates that the climate had changed from fairly humid to arid. The lake repeatedly deposited salt crystals along its shores and in the wet mud, but never were its waters so concentrated that continuous beds of salt were laid down. As shown by the annual layers the salt crystals formed only, at intervals of about 50 years, which indicates that the water level even then rose and fell through a considerable range as the rates of supply and evaporation varied.

While Lake Uinta had no outlet and its level was prevailingly low the organisms lived in so great profusion that their remains accumulated on the botton almost to the exclusion of anything else. But that this material endured long enough to be covered and so preserved means that it won a race with a host of bacteria and other scavenging hordes eager to destroy it. In that race, however, it suffered partial decay; the individual organisms lost their identity and melted away into a jellylike ooze, which finally became so charged with the toxic products of decay that it became intolerable even to bacteria. When decay finally ceased, the ooze became an excellent preservative, protecting from decay the delicate plants and animals that it accidentally entombed. As the organic ooze or gel was covered by successive layers and finally by thousands of feet of sediment it was compressed and gradually hardened into a dense substance resembling hard rubber. Geologists have examined this material under the microscope by grinding small pieces so thin as to be readily translucent. These thin plates of rock, suitably mounted on glass slides, show not only finely preserved microorganisms but in addition an odd assortment of wreckage, including the eyes of tiny insects, spatulate scales from mosquitoes' wings, and an abundance of pollen grains. When this hardened organic substance is heated it yields a distillate of crude oil from which may be obtained gasoline, fuel oil, and related products. Hence this substance derived from the former residents of the ancient lake is known as "oil shale". So plentiful were the microorganisms and so long did Lake Uinta persist that its deposits now contain locked up the equivalent of more than 70 billion barrels of crude oil waiting to supply the Nation's needs when the supply of petroleum from wells becomes inadequate.

Lake Uinta was blessed in its declining years by a return to conditions more nearly like those that attended its youth and middle life. Refreshing rain heartened the forest to make another stand, and the gradually expanding lake finally purged itself by overflow. Plants of the kinds that fared badly during the protracted drought gradually spread down from the hills and resumed their former habitats. But as the streams swelled and expanded the lake in this final stage, they brought with them an unwonted burden of waste from the land—waste that had accumulated during the dry epoch. Thus it came about that the lake was commonly turbid and could not provide, as formerly, the optimum environment for an immense population.

Moreover, the prime motivating force that brought Lake Uinta into existence and that made possible its long life was beginning to grow feeble. This force had been one of great magnitude, for it was this that had warped the crust of the earth gradually downward into the great basin-shaped depression which the lake occupied. And now that this force was weakening the streams were able to bring sand and silt into the lake a little more rapidly than the downwarping could make room for it. Hence the water became more and more shallow, and stream-laid deposits pushed ever farther and farther out into the basin until there remained only a vast alluvial plain dotted with swamps and small ponds. The streams that had so long paid tribute to Lake Uinta finally overwhelmed it and brought its rule to an end.

SELECTED BIBLIOGRAPHY

Bradley, W. H., U. S. Geol. Survey Prof. Paper 158, pp. 87–110, 1929; U. S. Geol. Survey Prof. Paper 168, pp. 1–56, 1931.

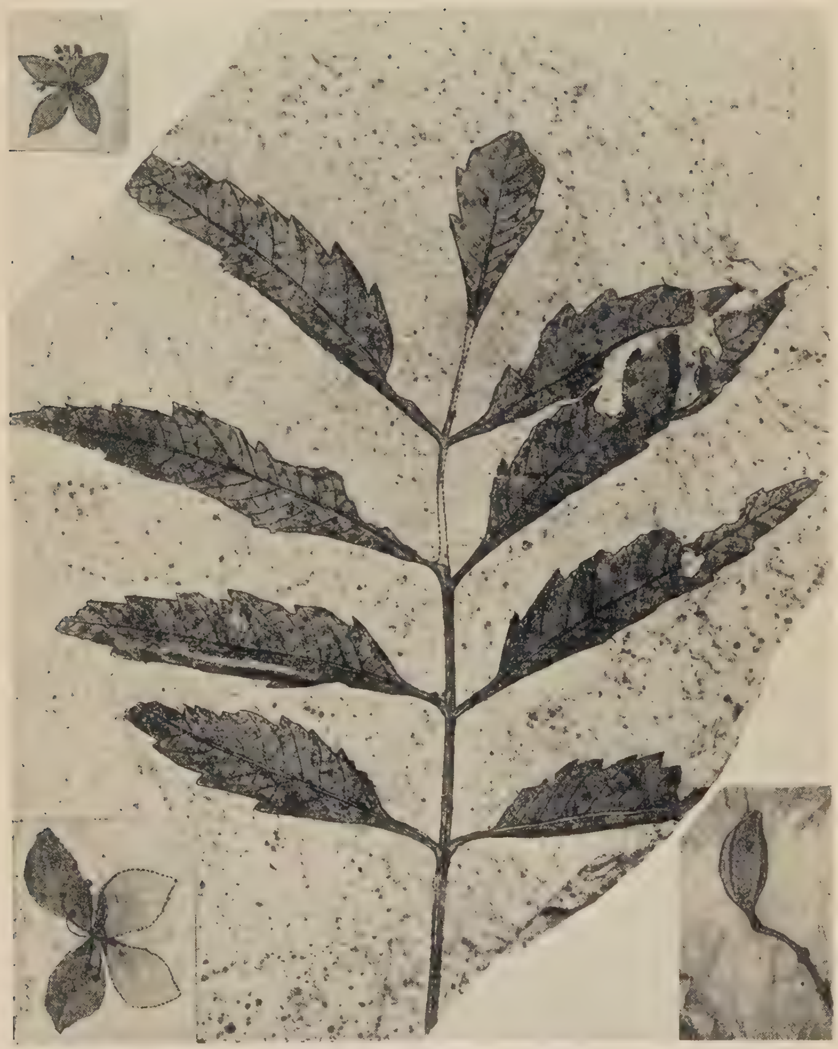
Brown, R. W., U. S. Geol. Survey Prof. Paper 154, pp. 279–291, 1928; U. S. Geol. Survey Prof. Paper 185–C, pp. 45–68, 1934.

Cope, E. D., U. S. Geol. and Geog. Survey Terr. Rept., vol. 3, pp. 1–100, and pls. 1–14, 1883.

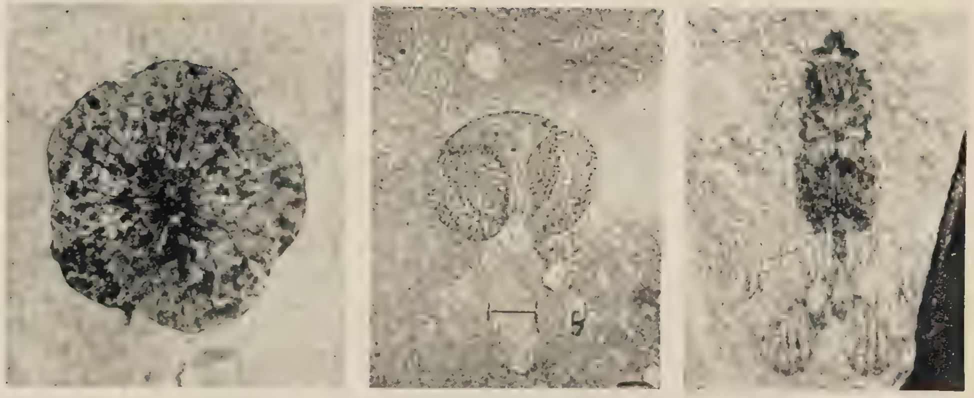
Scudder, S. H., U. S. Geol. and Geog. Survey Terr. Rept., vol. 13, pp. 675–686, and pls. 6–10, 1890.

Winchester, D. E., U. S. Geol. Survey Bull., 729, pp. 1–204, 1923.

Wodehouse, R. P., Torrey Bot. Club Bull., vol. 60, pp. 479–524, 1933.



LEAVES, FLOWERS, AND A SEED, EACH OF WHICH BELONGED TO A DIFFERENT PLANT THAT LIVED NEAR LAKE UINTA MANY MILLION YEARS AGO.

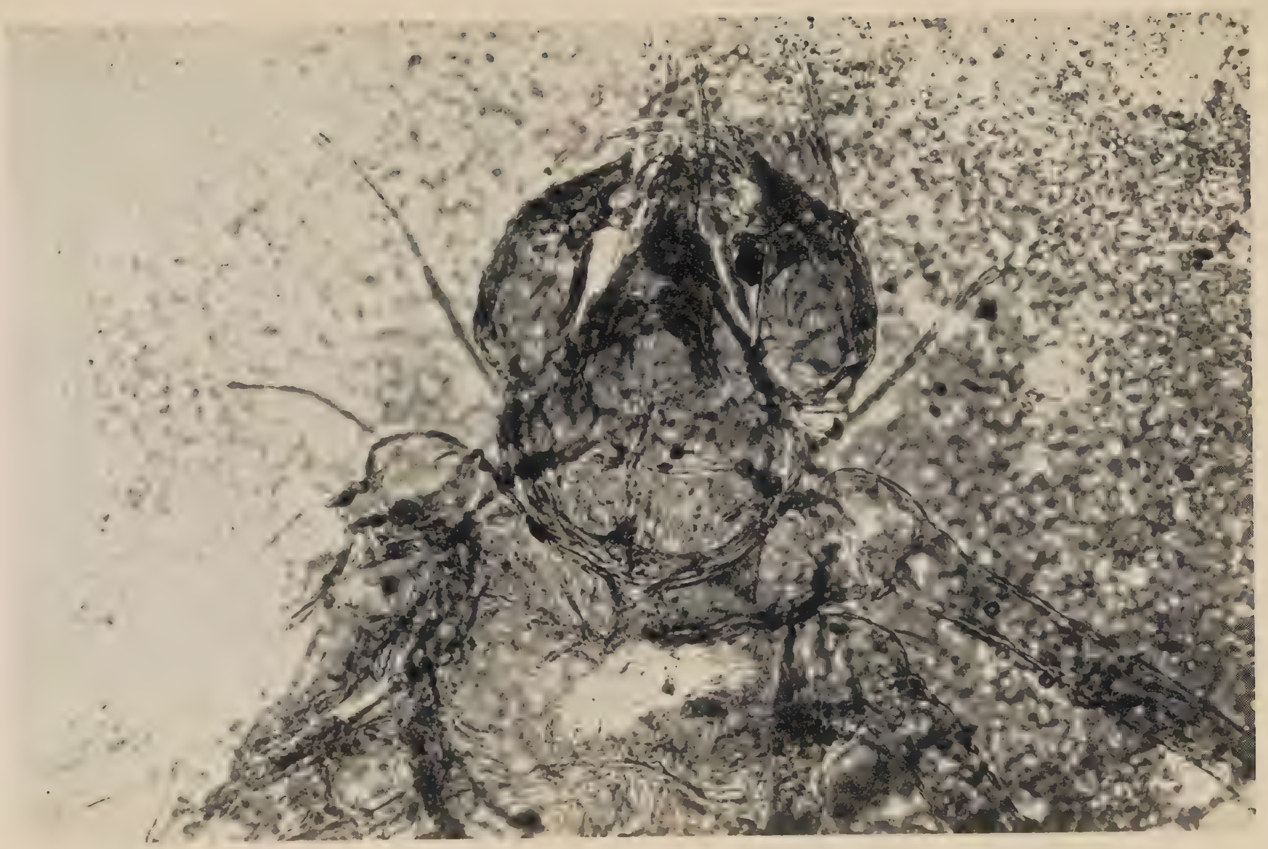


FLOWER, POLLEN GRAIN, AND A LEAF-HOPPER EMBEDDED IN ROCK.

Left: This delicate calyx of an ancient flower, probably related to our morning glory, grew near the shore of Lake Uinta and has been preserved in stone

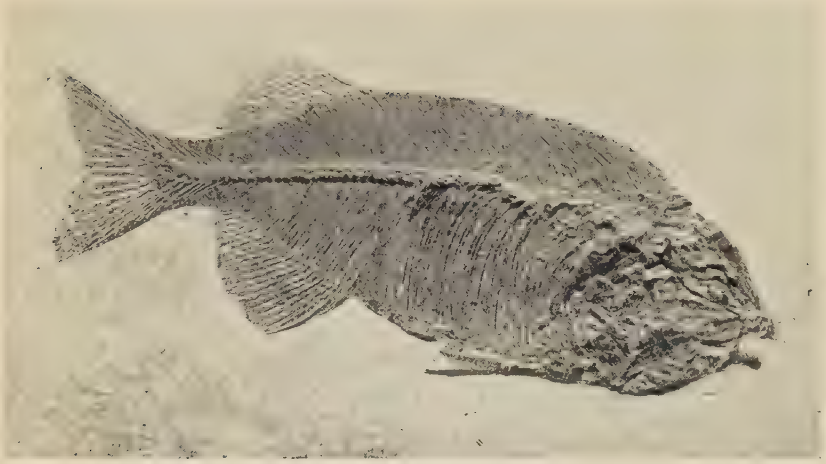
Center: A pine pollen grain from the ancient Lake Uinta. This single grain is greatly enlarged and shows the two rough-surfaced, bulging air sacs that enable it to float through the air far from the parent tree. The pollen grain is shown in its matrix of rock which was once black mud at the bottom of the ancient lake. This photomicrograph was taken by light transmitted through the rock after it had been ground so thin as to be translucent. Below the pollen grain is a bar scale one one-thousandth of an inch long enlarged the same amount as the pollen.

Right: A tiny leaf-hopper that some 30 million years ago danced above a gleaming mud flat only to have its wings and feet caught fast in the drying surface film. Its true size is about one-fifth of that shown in the photograph.



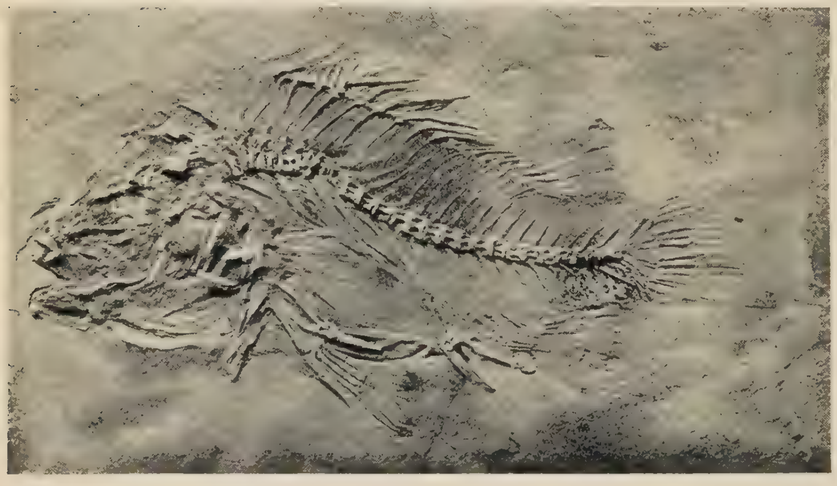
AMERICA'S OLDEST "LOUSE"—BUT NOT REALLY A TRUE LOUSE ONLY A RELATIVE. A PREDACEOUS MITE THAT LONG AGO FED UPON OTHERS OF HIS KIND NEAR LAKE UINTA. ITS HEAD IS ONLY ONE TWO-HUNDREDTH OF AN INCH ACROSS AT THE WIDEST PLACE.

Like the pollen grain shown on plate 2, the mite is embedded in rock that has been ground to a thin translucent slice.



1. AN ANCIENT FISH THAT ONCE SWAM IN THE WEEDY BAYS OF THE ANCIENT LAKE UINTA.

The photograph is reduced—the fish was more than a foot long.



2. ONE OF THE LESSER FRY OF LAKE UINTA—A FISH ABOUT 4 INCHES LONG THAT RESEMBLED OUR LIVING SUNFISH.

OUR WATER SUPPLY[1]

By Oscar E. Meinzer
United States Geological Survey

GENERAL CONSIDERATIONS

Water in relation to physical processes.—In the physical and biological evolution that has taken place on the face of the earth, water has had a unique function as the principal vehicle for the transfer of matter and energy. It appears that all evolution, whether physical or biological, requires, on the one hand, sufficient rigidity to supply a degree of stability and permanence, and on the other hand, sufficient fluidity or plasticity to permit more or less gradual change in response to applied energy. In the physical evolution of the earth there have been two major complementary processes. One has been the repeated raising of parts of the solid exterior of the earth to considerable elevations above sea level through deformation and the intrusion or extrusion of fluid or plastic rock material; the other has been the reduction and modification of the raised parts, chiefly, though not exclusively, through the agency of the water acting in its role as the transporter of matter and energy. Thus the development of the geologic structure of the outer part of the earth and the creation and re-creation of the land areas in all their characteristic detail, have been accomplished chiefly because the earth is surficially rigid but fundamentally plastic, and because there is a supply of water which has served as the principal agent in mechanical weathering, as the carrier of oxygen and other elements that are active in chemical weathering, and as the transporter of the weathered materials in suspension or solution with subsequent deposition of these materials and forming of the sedimentary deposits.

Although the poet may regard mountains as the symbol of eternal permanence, the geologist knows that they are ephemeral features which stand majestically for but a brief period, only to disappear under the erosive work of the water. To the geologist the work of the water is almost everywhere in evidence—in the sculpture of the land, in the character of the soil and subsoil, in the vast succession of sedimentary formations with their numerous unconformities witnessing to repeated cycles of uplift and erosion, in the texture of the rocks, and even in the mineral deposits within the rocks.

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[1] Address of the retiring president of the Washington Academy of Sciences delivered January 21, 1937. Reprinted by permission from the Journal of the Washington Academy of Sciences, vol. 27, no. 3, March 15, 1937.

Water in relation to life.—The work of water is no less evident in the evolution of the plant and animal kingdoms. The Cambrian strata contain the record of abundant marine life. In the half billion years that have elapsed since the Cambrian period, both plant and animal kingdoms have undergone vast evolution, with extensive and effective adaptation for life on the land and even in the most arid regions. However, in this long process of radical adaptation to different environments, no species of plant or animal has escaped from the fundamental requirement of a water supply in order to carry on its life processes. Deprived of water, all plants and animals would perish. Deprived of water, the human race, with all its thought and emotion and spiritual aspiration, would come to prompt oblivion.

When consideration is given to the narrow range of temperature and other conditions that are required to provide a utilizable supply of water to living creatures, it seems evident that relatively few heavenly bodies are adapted to support life as it is known to us. Nevertheless, in the inconceivably large multitude of heavenly bodies there may be, in the aggregate, many that have the proper conditions for a water supply and that support living creatures comparable with those that exist on this earth, or that existed in the Cambrian period, or that will exist in ages yet to come. Moreover, it seems reasonable to believe that there is a spiritual character to the universe which has a reality and means of expression that are not limited by the special physical conditions found on this earth. But, however incidental water may be in the ultimate plan of the universe, for life on our own earth its need is fundamental and inescapable.

As the plant and animal kingdoms moved in large part from the sea to the land, radical adaptations to their changed water supply resulted. Thus it became necessary for both the land plants and the land animals to adapt themselves to the use of fresh water instead of salt water, and this adaptation has become so thorough that now salt water means death to nearly all land life. Thus also was developed the constant-temperature adaptation of the warm-blooded animals, operated by means of water acting as the medium for transporting energy in the form of heat, and this has led to parental care and prolonged adolescence, and ultimately to the fruition of intellectual and social evolution in the human race.

Water in relation to human activities.—With advancing civilization the human race has found water to be a most convenient substance for a large and ever enlarging list of uses. Indeed, its several properties, such as its solvent properties, its high specific heat, its occurrence in the solid, liquid, and gaseous states within convenient temperature intervals and with high latent heat in passing from one state to another, lend themselves so remarkably to the needs of civilized man in his multitudinous domestic and industrial operations, recreational activities, and therapeutic applications that it seems as if these properties had been providentially designed for the benefit of man. It is an interesting exercise to make a list of the uses to which water is put by man, many of which are analogous to the physiological uses of water by living organisms, as for example, the conveyance and storage of material and energy, often with resultant chemical changes, the regulation of temperature, and the elimination of waste. It will be noted that in most of these uses, water serves as the vehicle for conveying either matter or energy. It is not surprising that water has acquired a unique religious significance as the symbol, in the rite of baptism, of spiritual cleansing and regeneration by the washing away of all sin.

The average per capita consumption of water in the cities and towns of the United States amounts to more than 100 gallons a day. Some of this water is wasted but most of it is used for beneficial purposes. In the future the volume so used will be increased and new uses will be developed. Thus, the rapid advance in air conditioning of buildings is producing an almost alarming increase in the demand upon our public water supplies. It may therefore be expected that, even with reduction in waste, the consumption of water will increase with advancing civilization. One of the truly great achievements of civilized man is that of providing, for human use, abundant, convenient, and reliable supplies of water of good quality. Indeed, the improvement of the quality of the water supplies has been a major factor in increasing the average length of human life. However, considering the less advanced countries of the world and the rural sections of our own country, it is evident that the task is still far from being completed.

The ultimate water supply.—The great residual reservoir of water is the ocean, which contains all except a small percentage of the external water of the earth, the rest being on the surface of the land, or in the interstices of the soil and rocks, or in the atmosphere. It is necessary to distinguish between the external and the internal water, for there is evidence that water is one of the constituents of the magma that forms the interior of the earth, and the total quantity of this internal magmatic water may be very great. The supply of external water is apparently being augmented by the extrusion of internal water and possibly by acquisition from outer space. There are also processes in operation which release water from chemical combination, but these are compensated more or less by processes which tie up some of the existing external water. Any attempt to evaluate these several processes would be quite academic. It appears that any changes which may have occurred in the total quantity of external water have not had effects of major importance within the period of definite geologic record. It also appears that no changes are in prospect that will affect appreciably the future affairs of man. Although the total quantity of external water has apparently not changed significantly, fluctuations in sea level, probably due to other causes, have been of primary importance throughout geologic history, including relatively recent time. Indeed, many of the large cities of the earth are at present situated below the levels of strands that have been washed by the sea since the human race began to live on the earth.

The hydrologic cycle.—The water that is of principal concern to man is the land water—the water in the lakes and ponds and in the brooks and rivers, the water that forms the soil moisture, the water in the rocks that supplies the springs and streams and wells. Any natural or artificial change that increases the supply of land water where it is needed, eliminates it where it is destructive, improves its quality, or increases its availability is a distinct human gain; any change in the opposite direction is human impoverishment.

The land water is not a stationary supply but forms a part of an ever-recurring circulation of great complexity and variation, which is known as the hydrologic cycle. The prime mover in this cycle is the sun, which, in the last analysis, furnishes the energy that evaporates water from the sea and conveys it as vapor to higher elevations on the land, where it is precipitated, chiefly as snow or rain, with potential energy that tends, through the force of gravity, to carry it back to the sea. The solar energy is also applied in causing evaporation from the lakes, ponds, swamps, and streams, from the land surface, from objects on the surface, from the soil, and, by transpiration, from the leaves of growing plants, including the native and cultivated trees, shrubs, and herbs. Indeed, the records of precipitation and run-off show that only about a third of the water that falls as rain or snow in the United States reaches the sea as run-off—about one-half in the eastern part of the country, only a small percentage on the Great Plains, and none in the Great Basin.

In its return course, the water flows over the land surface and through the stream channels and percolates through the interstices of the soil and the water-bearing formations. In its course it performs work of great variety, some of which is beneficial and some injurious to man, and much of which has been modified for better or worse by the intelligent or unintelligent activities of civilized man.

Thus the hydrologic cycle consists of two phases—one phase including evaporation, atmospheric movement of the water vapor, and ultimately its condensation and precipitation upon the land; the other phase including the movement and temporary storage of the precipitated water upon or under the land surface while on its way to the sea or to points of re-evaporation on the land. Both phases are very complicated.

FIRST PHASE OF THE HYDROLOGIC CYCLE

Natural fluctuations in humidity and aridity.—Let us consider the first of these two phases of the hydrologic cycle. The terms *aridity* and *humidity*, as the opposite of *aridity*, are difficult to define in precise terms. In a widely accepted sense, however, the term *aridity* relates to the deficiency of the precipitation in a given area for the normal growth of mesophytic vegetation that is otherwise adapted to the conditions of that area. In this sense the aridity of an area is intensified by decrease in the amount of precipitation and also by increase in the evaporativity of the area—that is, in the potential rate of evaporation. Both precipitation and evaporativity vary radically from place to place and from time to time, largely because of temperature variations, which are produced by a complex of different causes.

The geologic record, covering some hundreds of millions of years, seems to show that long ages of relatively warm and equable climate, perhaps with a general tendency toward aridity, were at several times interrupted by shorter periods of more variable climate including some cold, humid stages. The latest of these variable periods began, perhaps a million years ago, with the first of the Quaternary glacial stages and is apparently still in progress. The geologic record shows that the Quaternary, and perhaps also older periods of the same sort consisted of several major glacial stages alternating with distinct interglacial stages, and that the glacial stages, or at least the last one, consisted of two or more substages involving considerable climatic fluctuations. The greater humidity of the glacial stages was in large part caused by decrease in evaporation. From biological evidence and the evidence of marine terraces, it appears that we are at present in an intermediate position, having receded only part of the way from the last glacial stage. From intensive study of geologic, archeological, and historical records it is, however, evident that recent time has not consisted of a gradual change from glacial to interglacial conditions, but rather of complicated fluctuations of climate, in part regional rather than world-wide, between periods that were more humid and periods that were more arid than the present.

All about us we have impressive evidence of climatic change, such as the great sheets of glacial drift and trains of outwash gravel, the scores of desiccated or partly desiccated lakes, including the extensive Lakes Bonneville and Lahontan, and the great mantle of loess or wind-blown silt that covers much of the interior of this country and is largely responsible for its great fertility. Looking more closely at the evidence of fluctuations furnished by existing lakes, glaciers, tree rings, etc., and the available records of measured precipitation and stream flow, we stand impressed by the great and irregular climatic variations of the immediate past.

Thus at the end of the disastrous drought year of 1936, we in this country look into the future somewhat bewildered and almost afraid, the more so because we recognize that much of the productive part of our country is not very far from the margin of semiaridity. We must frankly admit that in spite of all our investigation we do not know in which direction we are trending—toward greater humidity or more severe droughts—in the ensuing year, decade, or century. We can, however, make some predictions, which are in part reassuring and in part otherwise. It is virtually certain that drought conditions are not permanent but will be followed by years of abundant rainfall and bounteous crops; on the other hand, it is almost equally certain that the recent droughts are not abnormal but that in the course of time other droughts of equal and even greater severity may be expected.

It is believed that the climatic fluctuations of the past have been the underlying cause of much turmoil in human history. But it is significant that the human race has not only managed to live through the times of drought and the intervening cold and wet times, but also that it has had its notable evolution in this Quaternary period of strongly fluctuating climate. The climate of the present, as the climate of the past, challenges man to greater effort and achievement.

The possible influence of artificial changes upon precipitation.—When, during periods of wet years, the settlers moved into the semiarid region of our country and found to their delight that they could raise good crops, they fondly developed the faith that rainfall follows the plow. Now, after a series of years of drought and crop failure this faith has been sorely tried; and we are tormented with the fear that on account of the acts of man in plowing and draining, our country is rapidly becoming a desert. In the presence of such intense public concern it is difficult to maintain a wholly judicial attitude. It is reasonable to expect that fluctuations in humidity such as are known to have characterized the past, should also occur, through wholly natural causes, in the present and future. This logical inference, however, does not afford any reason for assuming that the very extensive and radical changes which have been made by the white men on the face of our country have produced no effects toward greater humidity or aridity. Neither may it be assumed that such effects can be of no practical consequence if they are obscured by natural fluctuations.

If the average annual contribution to the precipitation upon a continent from water evaporated out of the sea remains the same, then the drainage of swamps should reduce the average annual precipitation because some of the swamp water that would normally be evaporated and reprecipitated is drained away into the sea. On the other hand, the diversion of water from streams that flow into the sea and the use of this water for irrigation should tend to increase the precipitation. Moreover, any changes incident to cultivating and cropping the land or to grazing the land should decrease or increase the precipitation according as they increase or decrease the run-off into the sea. It is generally believed that these artificially produced changes in run-off cannot be quantitatively competent to produce appreciable changes in precipitation. However, it is pertinent to inquire whether they may have significant effects in some critical areas. It would seem that the subject deserves serious investigation.

SECOND PHASE OF THE HYDROLOGIC CYCLE

Return flow and storage en route.—The other phase of the hydrologic cycle consists of the flow of the precipitated water toward the sea or toward places of reevaporation from the land, and its storage en route, chiefly as ice and snow, as surface water in the lakes, ponds, and swamps, as moisture held by molecular attraction in the soil, and as ground water in the subterranean reservoirs formed by the porous rocks. To the extent that the storage facilities are inadequate, the precipitated water is rapidly discharged into the sea through the natural drainage channels as direct run-off. This direct run-off is of little value to man and it produces most of the destructive floods and most of the destructive erosion and sedimentation. If there were no natural storage facilities there would be virtually no springs, no perennial streams, and no trees, grass, or crops, and all stream channels would be subject to sudden and violent floods.

Near the close of the last century it became evident in this country that accurate continuous records of stream flow were essential for efficient utilization of the water resources and for effective flood control. Since that time a large amount of systematic stream gaging has been done, with accuracy increasing from year to year. Intensive studies have also been made to differentiate between the direct run-off and the run-off derived from the several kinds of storage, and to determine the laws of each and their relation to precipitation. In some of the coastal regions large quantities of ground water are also discharged into the sea without appearing at the surface, such discharge being controlled by the geologic structure, the permeability of the water-bearing formations, and the balance between the head of the ground water and the back pressure of the heavier sea water.

Civilized man has made a notable achievement by supplementing the natural storage facilities with many artificial reservoirs, both great and small. Unfortunately, this achievement is likely to prove less substantial in the long run than is popularly supposed, chiefly because of the rapid accumulation of sediment brought to the reservoirs by the turbid waters of the direct run-off. Much careful study has already been given and much more is needed to determine the rates of sedimentation under different conditions and to devise feasible methods of prolonging the life of reservoirs by bypassing the most turbid waters, by sluicing out the sediments, or by other means. Much progress has recently been made in the appreciation of the great value of the natural storage facilities and the importance of conserving and utilizing them. The whole complex subject affords a large field for future study and constructive effort.

Ice and snow storage.—Ice and snow have recently come into the scientific limelight in different ways. One of these relates to the interest of geologists in the relation of the Quaternary and older glacial stages to fluctuations of sea level and to the cyclic character of some of the stratified rocks of marine origin. Thus it is now believed that in some of the glacial stages enough water was locked up as glacial ice to depress the sea level as much as several hundred feet, and that, on the other hand, many of the ancient sea terraces, such as occur on the Atlantic and Gulf Coastal Plain, were formed during interglacial stages when there was even less ice than at present. It has been estimated that if all the ice that exists at present in the polar regions were melted it would raise the sea level at least 100 feet and perhaps 200 feet or more. The advance and retreat of existing European glaciers have long been recorded, but systematic observations on North American glaciers have only recently been undertaken. Interest in snow relates chiefly to the snow in the mountains, which supports the summer flow of many streams, and to recently developed methods of estimating the annual snowfall and predicting the resultant stream flow.

Storage of water in the soil.—A soil may be regarded as a water reservoir, its water being in the form of moisture adhering to the soil particles. This water is under complicated stresses produced by combinations of the molecular attraction of the soil, the downward pull of gravity, the absorptive energy of the plants, and the energy involved in the relation between the soil moisture and the atmospheric vapor. The slow movements of the soil moisture in response to these stresses are of much importance in plant growth and in recharge of the water-bearing formations, and they have properly been the subject of much study.

The value of a soil for producing crops depends largely on its capacity to hold its water supply against the pull of gravity and yet to yield this retained water to the roots of the plants. A clean dune sand retains so little water that even in a humid region it may support only cactus and other drought-resistant plants; on the other hand, a clay soil has a large water-retaining capacity but may hold most of its water in dead storage insofar as the roots of the plants are concerned. Between these extremes are the productive soils of intermediate texture, such as the loams formed from the loess, which hold considerable water against the pull of gravity and yield it freely to the plants.

Dry-farming methods consist largely in utilizing the reservoir capacity of a soil by storing in it the rain and snow water of one or more years and making it available to a crop that is grown in a much shorter period. Unfortunately, soils do not generally have the capacity to store the quantity of water that is needed to produce a crop without replenishment by rains or irrigation at more or less frequent intervals during the growing season. In the eastern and especially the southeastern part of this country it frequently happens that the soil moisture is fully replenished early in the winter and that for many weeks thereafter water from the rain and snow percolates through the soil without adding to its water content. In the ensuing summer, however, the soil moisture may become depleted long before the crops have matured, and severe drought damage may result.

Agriculture is, from the viewpoint of this discussion, one of the greatest of all achievements of man in the utilization of our water supply, but soil erosion, like a dread disease, gnaws at its roots. The erosion of the soil removes a part of the water reservoir that it utilized in crop production, and especially the upper part, which generally has the greatest capacity for holding water available to plants. Thus the measures undertaken to check soil erosion are measures of water conservation.

Storage of water in the rock formations.—The systems of rocks that form the outer part of the solid earth are the products of all the diverse and variable geologic processes that have been operative through the ages. The description and interpretation of these rock systems, with their almost infinite complexity, is the task of the geologists. The rock systems constitute natural systems of waterworks with many reservoirs of great variety, some of which have very large capacity. The study of these natural waterworks and their operation is a task of the hydrologists. It is a task that has required the development of a distinctive technique in the application of the science of fluid mechanics and hydraulic engineering to the geologic structure of the rocks.

The porous and permeable rock formations which constitute the underground reservoirs are saturated below a certain level with water that is under the control of gravity. In other words, theu nderground reservoirs are filled to the level of the water table. In most places the roots of the plants do not extend downward to the water table or to the capillary fringe, which occurs directly above the water table, and there is therefore an intermediate belt between the root zone, or belt of soil moisture, and the zone of saturation.

Replenishment of the underground reservoirs.—The underground reservoirs are replenished, or recharged, with water from atmospheric sources. Nearly all hydrologists believe that the recharge is essentially all from rain and snow or from streams fed by rain and snow, but there are still a few hydrologists who believe that subsurface condensation is a substantial source. The amount of recharge from a given amount and kind of precipitation varies with the absorptive or intake capacity of the soil or other surficial material and inversely with the capacity of the soil to hold the water for plant use instead of allowing it to percolate downward to the water table.

The intake capacity constitutes a large subject with many ramifications. It includes questions as to the effects of the vegetable mold in the forested areas and of the natural sod, and, on the other hand, the effects of grazing and of the cultivation of the soil. It includes also the problems of artificial recharge by spreading stream water or by other means, and of the silting up of the natural recharge channels by surface storage or other manipulation. The surface conditions of both forests and sod-covered prairies are favorable to intake by keeping the rain and snow water clean and thus permitting it to percolate downward through the available ducts and pores without clogging them, whereas under some conditions the cultivation of the soil tends to decrease the intake capacity, especially in heavy and prolonged rains, by puddling the top layer of soil and choking the intake openings. However, forests consume large quantities of water by transpiration, which tends to offset their large intake. The conflicting results obtained by different investigators as to the effects of forests on the water table and on the flow of springs and streams, as compared to the effects of cleared or cultivated land, are in part due to the fact that in some places and at some times the balance is actually on one side and in others on the other side. Relatively little investigation has as yet been made of transpiration on the sod-covered prairies and of the effects of breaking up and cultivating the prairie lands. It appears probable that there is a basis in fact for the prevalent belief that the advent of the white men in this country was attended by a certain amount of lowering of ground water levels and of decrease in the flow of springs and streams.

It appears that artificial recharge by water spreading, by impounding of surface water and regulation of stream flow, and perhaps by drainage into wells, has large possibilities for increasing the perennial supply of ground water in certain specific areas of heavy consumption in which the natural conditions are favorable. On the other hand, for the country as a whole, recharge by such means will remain small in comparison to the total natural recharge and the total discharge of ground water through stream flow and through evaporation and transpiration. Greater aggregate increase in recharge is likely to result from general improvements in agricultural practice and from structures designed to retard soil erosion.

Great as are the variations in precipitation from place to place and from year to year in the same place, the variations in ground-water recharge are still greater. It is now known, for example, that perennial supplies amounting to many millions of gallons a day are available to wells through natural recharge of the sand and gravel in the fill of the coastal valleys and the Great Valley of California, the glacial outwash sands and gravels of Long Island, the Rhine Valley and the plain of northern Germany, the dune sands of Holland, the creviced limestone in the Roswell artesian basin in New Mexico, the broken lava rocks of the Snake River Plain in Idaho and the islands of Oahu and Maui, and the water-bearing rocks of various other areas. On the other hand, there are areas in which ground-water recharge is extremely small, either because the surface terrane is impermeable or because the water absorbed from scant precipitation is nearly all evaporated or utilized by plants before it reaches the bottom of the root zone. Large areas in the arid and semiarid parts of this country have only very meager recharge because the precipitation is light and occurs largely in the growing season. Yet many of these areas are underlain by water-bearing formations that contain large stores of accumulated water which they will yield freely to wells so long as the supply lasts. In the coastal region of California and in the Great Valley the soil normally becomes desiccated during the long dry summers. In winters of subnormal precipitation the precipitated water is here largely required to restore the soil moisture, and there may be little ground-water recharge; in exceptionally wet winters, however, the water-retaining capacity of the soil is satisfied long before the end of the rainy season and very large quantities of water percolate to the water table, either locally through the soil or through the channels of the influent streams. In the relatively humid eastern part of the United States there is normally considerable recharge not only in winter and spring but also in wet periods in summer, but in the drought of 1930–31 some localities were devoid of recharge for nearly a year. In cold regions with only moderate precipitation nearly all the recharge may occur in a very short time in the spring when the snow melts and the frost leaves the soil. In such regions there are also great differences in the annual crop of ground water.

Relation of the water table to the plant kingdom.—It has already been pointed out that in most places the roots of the plants do not obtain their water supply from the zone of saturation. Throughout the greater part of the extensive and productive interior agricultural region of our country, the staple crops depend on the soil moisture derived directly from the rain and snow and fail if that supply becomes exhausted, regardless of the quantities of water that are stored below the water table. On the other hand, however, water from the zone of saturation is utilized, either habitually or in times of drought, by native and cultivated plants in many low places, including large parts of the Atlantic and Gulf Coastal Plain, the glaciated region, and the stream valleys and structural valleys in other parts of the country. Thus the relation of the water table to forest and fruit trees, staple crops such as wheat, corn, and alfalfa, garden truck, and native grasses is a subject of great consequence.

It is estimated that in the eastern part of the United States at least one-third of the water discharged from the zone of saturation is discharged by transpiration or evaporation, the rest being discharged chiefly as stream flow. In some of the summer months the discharge by transpiration and evaporation may greatly exceed the discharge by stream flow. In going toward the less humid parts of the country the total annual supply of ground water decreases but the proportion discharged by plants increases, until in some of the arid sections virtually all the water discharged from the zone of saturation is through plants, and the phreatophyte vegetation, which taps the zone of saturation, stands in striking contrast to the other desert plants.

Probably the greatest deficiency in hydrologic knowledge, especially in this country, is in the important practical subject of the relation of the native and cultivated plants to the water table. Not enough attention has been given to the water table by botanists, silviculturists, or agronomists, and adequate information is not available on such important subjects as the phreatophytic habits of trees and their relation to forestation in the arid and semiarid regions, the depth to which different cultivated plants will extend their roots to reach the water table, the optimum depth to the water table, and the increase in crop production resulting from use by the plants of water from the zone of saturation. The intensive drainage developments that have been made in this country have been based too largely on the concept that the water table is a detrimental feature, and not enough consideration has been given to the value of the water table to plants under proper conditions. On the other hand, the inadequacy of specific information on this subject is largely responsible for exaggerated statements that are made from time to time as to the disastrous results to agriculture from general lowering of the water table.

Relation of underground storage to stream flow and to water supplies from wells.—The principal function of a reservoir is to store water for future use. The underground reservoirs function naturally like lakes and ponds in equalizing the stream flow, but they are more effective because of the retardation of the ground water by the friction of the rock interstices. Underground reservoirs of some sort are almost universally present and are chiefly responsible for the sustained flow of streams. The ground-water run-off carried by the streams is relatively constant as compared with the very erratic uncontrolled direct run-off, but it is nevertheless sensitive to various weather conditions and is generally greatly reduced by severe drought. Streams differ greatly in the quantity and fluctuation of their ground-water run-off according to the geology and other natural conditions of the drainage basins. A subject that has received little investigation but is of much scientific and practical interest is the relation of geology to stream flow.

The underground reservoirs function like artificial reservoirs with controlled outlets only when they are tapped by wells that extend considerably below the water table. Shallow wells that merely skim off ground water from the top of the zone of saturation are likely to fail when the water table is lowered by drought, but the wells that extend deeper into the water-bearing formations and have access to their great stores of water are not appreciably affected by drought. Reports of failure of such wells are commonly due to mechanical defects in the wells or pumps, or to attempts made in times of drought to increase the rate of pumping beyond the normal capacities of the wells. By drawing water from wells in proper amounts the storage facilities of the underground reservoirs are utilized and ground-water recharge is increased.

Yield of the artesian reservoirs.—A problem of great practical significance relates to the perennial yield of the underground reservoirs. To what extent is the water that is annually being drawn from pumped or flowing wells derived from annual recharge and to what extent is it taken out of storage, with the prospect of ultimate serious depletion? From which of the water-bearing formations can additional perennial water supplies be developed and where can these developments be made? These questions are more intricate for the artesian formations, which are under confining covers, than for the water-bearing formations that have water-table conditions and hence have their wells in or near their intake areas. They are also more intricate for the extensive artesian sands and sandstones, which transmit their water through small intergranular interstices and exhibit considerable volume elasticity, than for the artesian limestones and lava rocks, which have much larger water conduits and are more rigid.

Among the large artesian sandstones of the United States are the Cambrian sandstones of the interior, the St. Peter sandstone, the Dakota sandstone, and the series of thick sands or sandstones of the Atlantic and Gulf Coastal Plain. In these sandstones centuries may be required for water to percolate from the intake areas to the localities of the wells. The total quantities of water that they hold in storage are indeed very large, and the quantities that they will yield from storage merely through the compression that results from the release of artesian pressure of the confined water apparently may amount to millions of gallons a day for many years. It is believed that the phenomenon of compression with decrease in artesian pressure has been demonstrated to be of primary importance in the study of the perennial yield of these artesian sandstones, but the mode of compression has not been given much investigation. Presumably compression occurs largely in the strata of relatively fine grain which feed into the strata of coarser grain that supply the wells. The phenomenon of reexpansion with increase in artesian pressure is also known to occur to a considerable extent. It is more difficult to explain than the compression but is probably also more characteristic of strata of relatively fine grain than of the most productive water-bearing beds.

It appears that the spectacular discharge of artesian water from the Dakota sandstone for more than half a century has been supplied to a great extent from storage, largely as a result of the elastic or compressive properties of the system. It remains to be determined whether the more moderate withdrawals that are likely to be made in the future will be replaced by recharge or will result in further progressive depletion. The 800-foot sand in the Atlantic City area has yielded water freely for several decades and is currently yielding several millions of gallons a day. It shows encouraging recovery of head whenever the rate of pumping from wells is diminished. However, a 13-year record obtained by the investigators in that area seems to show that the regional cone of depression is still expanding, and that with the resulting compression some water is still being taken from storage. Other great artesian sandstones, such as those which for many years have furnished the water supplies of Memphis and Houston, are known to have large annual recharge, but nevertheless further records are needed to determine definitely the source of the current pumpage—to what extent the pumped water is replaced by recharge and to what extent it is derived from storage by the further development of the regional cones of depression.

About 6,500 public waterworks in this country are supplied from wells. Many of these obtain their water from surficial formations with true water-table conditions and many others from recognized artesian formations. However, there is another large group of waterworks that are supplied from aquifers, largely in the glacial drift, that are not usually regarded as artesian and yet underlie more or less effective confining beds and are recharged by somewhat devious percolation of the ground water. More attention ought to be given to the problems of depletion and safe yield of these aquifers of intermediate character.

EMERGENCE OF HYDROLOGY AS A RECOGNIZED SCIENCE

The hydrologic cycle, being of major scientific and practical interest, has received the study of a large number of scientists, most of whom have not called themselves hydrologists. In this country the Weather Bureau long ago established a comprehensive and systematic program that has resulted in the accumulation of a great amount of base data on precipitation and other weather conditions, the value of which is beyond estimation. The Geological Survey has developed a thorough technique for gaging streams and has accumulated a remarkable body of systematic and exact data on stream flow. By systematic work through many years it has also made substantial achievements in the chemical analysis of the natural waters, in a general survey of the ground-water conditions, and in the development and application of quantitative methods in ground-water investigation.

In addition to the work of these two scientific bureaus of the Federal Government, there has been a vast amount of work by a great number of governmental and private agencies and individuals that has contributed in many ways to the base data and to the methods and principles of hydrology. Thus, many hydraulic engineers have devoted much of their time not to engineering work at all but to scientific research relating to the natural waters; thus, also, many other scientists, such as soil scientists, agronomists, geologists, botanists, and foresters, have made distinct contributions to hydrology. There has, however, been a lack of coordination, and developments have been made which have had unfavorable effects that were not foreseen because the scientists and engineers concerned did not have an adequate appreciation of the unity and complexity of the hydrologic cycle.

In recent years there has arisen a wholesome recognition of hydrology as a comprehensive science, and a general effort has been made to correlate the different aspects of the subject. This trend has found expression and stimulus in the organization, 6 years ago, of the section of hydrology of the American Geophysical Union. More recently an attempt has been made through the efforts of the Mississippi Valley Committee, the National Resources Committee, the State planning boards, and other agencies to evaluate objectively the manifold works of man that have affected the hydrologic cycle at some point and to attain a clearer perspective for the future. Thus, progress has been made in an appreciation of the sensitivity of our water supply to many complex controls. Looking to the future, we must insist that engineering works or other developments shall be undertaken only after their hydrologic consequences have been fully studied, and we must resolutely set ourselves the task of building a science of hydrology that will be adequate for the responsibilities that are involved.

THE FIRST CROSSING OF ANTARCTICA [1]

By Lincoln Ellsworth

[With 9 plates]

It is with a deep sense of the modesty of my own endeavors that I appear before you tonight to tell you something about my recent flight across Antarctica. It is 23 years since I last was in London. I wanted to become an explorer, so came over here to buy the necessary instruments, which at that age I thought would be the necessary qualification, but found that I must also take instruction, which I did, under Mr. Reeves, of your Society. Strangely enough, the pocket compass with which I practiced route-surveying on weekly excursions about the suburbs of London I carried and used on my flight across Antarctica last season. I prize it highly because, after all, it remains the memento of a visit that was to decide my whole future career. Had it not been for that beautiful emperor penguin which I visited weekly at the London Zoo and the memorial service which I attended at St. Paul's in February 1913 for Captain Scott and his gallant comrades lost in the Antarctic, I should probably never have chosen the polar regions as my field of endeavor. But so deeply stirred was my imagination by what I had seen and heard that the die was cast before I left London.

The dreams of youth are long, long dreams; yet despite all disappointments and setbacks that were to ensue, the purpose held, until a chance meeting with Amundsen made possible an airplane flight over the polar sea. My meeting with Amundsen was in 1924. Our flight the following year to within 120 miles of the North Pole, from Spitsbergen, was the first penetration of the polar regions by means of an airplane. It proved the value of aircraft as a future means of polar exploration.

After my flight with Amundsen in the *Norge* from Spitsbergen in 1926, over the north polar basin to Alaska, restlessness and desire nagged me until I was able to settle on the last great adventure of south polar exploration: The crossing of Antarctica.

A crossing of the area between the Ross Sea and the Weddell Sea seemed to offer the best possibility of solving the major problem in the Antarctic. Does the Andean massif which dips at Magellan Straits, rises to form the grand mountain chain of Graham Land, and dips at what is believed to be Stefansson Strait, rise again in Hearst Land and continue until it joins the polar plateau and the mountains of South Victoria Land; or, if it does rise in Hearst Land, does it dip again to form a depression or a below-sea-level channel connecting the Ross Sea with the Weddell Sea?

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[1] A paper read at the evening meeting of the Royal Geographical Society, November 30, 1936. Reprinted by permission from the Geographical Journal, vol. 89, no. 3, March 1937.

Numerous plans and many preparations had been made to carry out a trans-Antarctic journey. Shackleton in 1914 lost his ship before he reached the starting point. Wilkins was foiled 2 years in succession by failing to find a suitable airplane field from which to start. Watkins, after much preparation and endeavor, failed to get started from England. Riiser Larsen was carried away from the barrier edge by the breaking up of the ice, and did not get started on the actual journey.

By the time I was able to turn my attention to the problem, a great advance had been made in the machinery for aerial transportation, and I believed that it was no longer necessary to risk the lives of many men who by their sheer physical endeavor would fight their way slowly through storms, starvation, blizzards, and snow blindness, struggling for many weeks against tremendous odds across what might prove to be a monotonous stretch of sastrugi-featured snow: or, if mountains were found to exist between the Weddell Sea and the Ross Sea, find themselves in a maze of overhanging glaciers, steep-sided valleys, and faced with unscalable cliffs such as could be seen in Graham Land.

I myself would have preferred to have been with the vanguard of polar explorers, and am happy in the knowledge that neither the North Pole nor the South Pole were first humbled by conquest by airplanes. Nevertheless, it would not do for us to lag behind the times. Change is the law of the world itself.

> The hills are shadows, and they flow
> From form to form, and nothing stands.

says Tennyson. And so our method of approaching the mystery and romance of Nature's last stronghold against man's invasion had to change.

My own experience with airplanes in high latitudes had given me some knowledge of the possibilities of aircraft in polar conditions. I knew that low temperatures would not be a great obstacle to flight. I had experienced the fact of landing far from my base and setting out again for a safe return. I knew that aircraft engines in 1932 were reliable for many hours' service without overhaul, and I had studied carefully the Antarctic conditions as far as they might affect the use of the airplane.

In spite of the general impression created by the books on Antarctic travel, which are filled with descriptions of bad sledging trails, hazy outlines, sudden blizzards, and hard-lipped sastrugi, I found that even the written accounts of previous expeditions really encouraged the belief that machines might be landed safely on most of the surfaces encountered in the past. A thorough search through the diaries of Scott, Shackleton, Mawson, and Amundsen revealed that the surfaces they found on their sledge journeys, both on the Ross Barrier and on the polar plateau, would afford reasonably good landing fields for modern airplanes, provided of course that the weather was such that these surfaces could be seen.

For instance, in Scott's published diary of his journey to the Pole he mentions soft snow, heavy and rough surfaces, and some surfaces distinctly good, but he actually mentions sastrugi on 5 days only during the 30 days it took him to travel from the edge of the Barrier to the foot of the Beardmore Glacier, which leads up to the polar plateau. Only on one occasion did he mention sastrugi 12 inches high, and then they were "widely dispersed." The other sastrugi seen must have been lower and probably would not have interfered with the safe landing of an airplane. From this it was clear that only a small percentage of the actual Barrier surface would be unsuitable for forced landings.

On the way up the glacier, Scott mentions sastrugi "not more than 3 inches high." There were crevasses and undulations and soft spots of course; one would expect to find these in the fairly steep-sloped area leading up to an altitude of 9,000 feet. But it was hardly necessary to consider the glacier surface in relation to Antarctic flight, for any airplane flying over them would, in case of engine failure and a forced landing, be able to glide above the glacier surface to the lower level of the Barrier.

When once over the plateau and beyond the "third degree" camp, Scott found the surface difficult for sledging, but not until after 5 days' marching did he come to sastrugi which were rough and confused—it was so rough, in fact, that Scott decided to abandon his skis, which he had used up to that time. But the rough condition was limited in area—a cross-section of probably less than 5 miles; for when they came to the end of the sastrugi, Scott says they went back for the skis, a trip which resulted in a delay of only 1 hour and 30 minutes. Onward to the Pole, and between the dates January 7 and 17, sastrugi are mentioned only four times, and then only in relation to the general direction of the winds. He refers to rough surfaces only once, on the 15th, near the Pole, and there the sledges "bumped over the ridges."

In Amundsen's account of his journey from the Bay of Whales to the Pole, he mentions sastrugi only five times, and only when on and near the glacier, in the draw of the mountains, did he find the surfaces exceedingly rough.

The general description of the surfaces encountered by Sir Douglas Mawson and the members of his parties was not so encouraging; but then Sir Douglas was traveling in comparatively low latitudes, between 69° and 70°, and his route lay over the sloping ice-sheet not far from where it meets the open water; a condition likely to induce high winds, crevassed areas, and sastrugi. Mawson's Magnetic Pole party led by Bage traveled farther from the continental edge, but was not more than 120 miles from the sea. Bage mentions sastrugi only twice during the first 75 miles of travel, and lists the snowy wind-drifts only once as being 1 foot high; the others must have been lower. Later on he remarks on sastrugi 6 inches high, then for 3 days very few. After that they traveled for 5 days over fairly good surfaces, then he mentions "some old sastrugi", then "surface smoothly polished."

Notwithstanding the difficulties which were actually encountered by Mawson's sledging parties in the Adelie Land area, Bickerton did use an air-screw tractor, in reality an airplane minus its wings, and taxied it several times over a route 10 miles long. The surfaces on any part of that route if suitable for taxiing must have been suitable for an emergency forced landing.

It is only logical to assume that conditions inland from the Adelie Land coast would be somewhat similar to those found by Scott and Amundsen farther south. Therefore, in spite of the general impression, and after a careful study of all conditions met by sledging parties, it seemed that on a flight across Antarctica it would be possible to find at least as many emergency landing fields as one would expect to find on any transcontinental flight before the development of air routes.

The question, then, resolved itself not into one of safe landing fields, but whether one could distinguish a safe landing field from the air. There is no doubt about the difficulty of distinguishing the type of snow surface when the sky is clouded or during snowdrift and blizzards, but it is not difficult in sunshine. To avoid danger it would be necessary to fly only in clear weather. So the weather problem was the greatest to be faced in relation to the use of airplanes in the Antarctic. It was, in fact, almost great enough to prohibit any attempt to make a trans-Antarctic flight. Storms without warning had frequently overtaken foot travelers, but it was obvious that when flying it would be possible to see the approach of a storm at a greater distance than when on the ground, and also possible to turn away from it if necessary. The thing to do if a storm barred the way was to land and wait for clear weather.

But the high winds had wrecked tents and almost smothered polar parties, and, even before my plans were made, had ripped one of Admiral Byrd's planes from its lashings and carried it half a mile away. This was a high-winged type of plane, difficult to anchor, and it had been anchored to shallow snow on a glazed ice surface. But even had it been firmly made fast, its high wing would have left it at the mercy of the wind.

It was certain that insufficient data could be obtained from the Antarctic to allow reliable forecasting of the weather which might be encountered on the entire route between the Weddell Sea and the Ross Sea, and it was necessary, if I should attempt to fly over that area, to prepare to land in the face of bad weather. This plan required special attention to the type of plane to be used. First, I would need a plane with high speed, so as to limit the time risk as far as possible, and to overcome the high winds which would surely be met with in clear weather. The machine would have to be of a type which could be made fast safely to the ice or snow while riding out a blizzard. A low-wing type would serve that purpose, and one without struts or wires attached to the landing gear would best facilitate the lowering of the skis into channels dug in the snow and the digging out of the plane from the snowdrift when the blizzard was over.

In 1931, when my plans were first announced, there was no plane of the type I required, but a canvass of the possibilities showed that a development of the Northrop Alpha plane, a low-wing all-metal machine with cantilever streamlined landing gear, would best suit my purpose. At my request, the Northrop Airplane Co. built a special machine, the *Gamma*, for my service. It was large enough to carry sufficient fuel for a range of 5,000 miles if nothing but fuel and oil was to be carried; but naturally some of my load would consist of equipment and supplies. I intended to take enough for 2 months, so as to allow for repeated landings, and enough to serve even if we had in emergency to abandon the plane and walk to the nearest area which would provide food in the form of seals and penguins. The fuselage of the Northrop *Gamma* was large enough to accommodate a pilot and navigator, a sledge, skis and showshoes, sleeping bags, tents, engine covers, and heating stoves required for conveniently starting the engine in cold weather. The machine was, of course, equipped with a two-way wireless as well as an emergency radio outfit. The final design incorporated a 600-horsepower Wasp engine, giving a possible speed of 215 miles per hour. It had sturdy, short, and wide skis made of wood, sheathed with metal. The skis were interchangeable with wheels and pontoons, so that we might use the machine on any type of surface. A unique feature was the flaps, a very new feature in 1932, which permitted us to land at the comparatively low speed of 50 miles an hour and take off in a short distance.

After the airplane was selected it was necessary to find a ship which would accommodate the machine in the hold for safe transport through the stormy waters we should cross to reach the Antarctic. My first plan, based on the assumption that in the Ross Sea, at the edge of the great Ross Barrier, was the only place where I could be certain of finding an unloading point for the plane on skis, was to fly from the Ross Sea to the Weddell Sea and return on a triangular course.

My ship would have to brave the stormy areas south of New Zealand, and have sufficient range to journey round the Pacific sector of the Antarctic ice edge to pick me up, should I be compelled to land on the Weddell Sea side or abandon the plane en route and walk to some part of the coast. I finally selected a staunch, single-deck, motor-driven Norwegian fishing-boat of 400 tons. She was built of Norwegian pine and oak in 1919. I sheathed her with oak and armor plate for service in the pack ice. Her engine was of the semi-Diesel type, and I installed tanks for fuel sufficient for cruising 11,000 miles at a speed of 7 to 8 knots. I named the ship the *Wyatt Earp* after an unbelievably brave frontier marshal who more than any other man of his time typified the empire builders of the western United States.

The *Wyatt Earp* could carry supplies for 2 years as well as the airplane in the hold, where it was well protected from the weather. This left our decks clear, except for the explosive gasoline, which was carried in drums lashed to the deck rails. There was room, in fact, to have carried another plane on deck, but I finally decided against taking a duplicate machine for two reasons. First, by exercising infinite care with the machine while preparing it for flight, and by flying only in fine weather, landing only in clear weather, and in time to lash it down before being overtaken by storm, I could be reasonably sure of safety from damage. A skilled pilot, landing under such conditions would protect us from the danger of accidents to the personnel and leave us in a position to walk away from the machine if it was necessary to abandon it. Secondly, two airplanes would have meant two or more pilots and other additional members of the expedition, and in all an extra cost far in excess of the actual and initial cost of the machine.

Economy has not always been the first consideration in polar exploration and while it is necessary to spare no expense in providing adequate equipment, there is no reason why expeditions should be absurdly expensive or luxurious. It is impossible, of course, to value discovery in dollars and cents, but all attempts at discovery should be organized with some consideration for the magnitude of possible results compared with the amount of money involved. In this relation the use of airplanes has made it possible to lower the cost of exploration and discovery.

An expedition equipped for flying needs less personnel, and can expect to cover miles for less expenditure of energy and money than could be done when using the dog-team method. For detailed scientific research the dog-teams may be necessary, but my efforts were to be purely in the nature of discovery, to open the way for future research to follow. To achieve my purpose I believed that, by carrying sufficient food and equipment in the plane, we could, if required, spend several weeks on the journey, and if by chance our plane was wrecked, we could either hold out until my ship could return to civilization, pick up another plane, and come to our rescue, or else meet us at a predetermined point to which we might walk, and where we might find additional native food.

Adequate radio precaution would assure us of communication with our base at all times, and to cover this I prepared not only for two-way radio communication from the plane but carried as well a complete engine generator set for use when the plane was on the ground, and a complete hand-driven set for use when sledging. This, we believed, would take care of all emergencies. But we were wrong, for during our flight a terminal inside the sending set, and which we could not reach, burned out. While we were on the ground between flights we maintained the prearranged schedules three times daily, but the signals sent out by the engine generator set were never heard. The oil in the hand-driven generator froze stiff and stripped its gears.

Believing that we had ample fuel, we did not conserve our supply either when climbing to high altitudes over Hearst Land or during the various landings, and this brought us to a landing out of fuel when within 16 miles of our goal. There was no useful radio gear at Little America, and with a frozen foot and considering the difficulties of crossing the terribly crevassed area and pressure ridges which lay between Little America and our plane, I did not think it possible to haul equipment and fuel sufficient to bring the machine to Little America, where in time it might have been possible to repair the wireless set. So after the set failed, when we were about half-way across the Antarctic continent, we were out of touch with our base. We did, however, pick up time signals on three separate days from a station at Buenos Aires, and this made it possible for us to check up on our chronometers and establish our positions.

With the exception of our wireless, our equipment served its purpose admirably. There was no difficulty with the airplane equipment because of the cold. Wherever we landed on the plateau surface the snow was smooth and hard packed. The skis sank less than an inch, and we had no difficulty in landing or taking off, or in securing our plane so that it was safe during the blizzards we experienced. This shows that a carefully selected machine and suitable equipment, in the hands of a skilled pilot, will serve for preliminary reconnaissance in the Antarctic. Even in the mountainous areas we crossed in Hearst Land, there appeared to be many places, which would be difficult to reach by dog team, where we could have landed safely.

An airplane can carry more and bring back more specimens than a dog team could haul and although much time might pass while waiting for reasonably good weather, the speed of travel when the weather is good and the excellent visibility to be had when traveling by plane more than compensate for the delay. Therefore I think that with the airplane we can reveal the last remaining unknown regions on the face of the earth.

So much for our plans and the way in which they failed in certain points. The details of the flight have appeared already in the publications of American societies, but a brief summary of them will still be in place here.

In 1933 I had planned to make the flight in the opposite direction, from the Bay of Whales to the Weddell Sea, and in January 1934 had landed the airplane on the bay ice which, after a successful trial flight, broke up in a gale and crushed the machine so extensively that we had to abandon the attempt.

In September 1934 we were back in New Zealand ready for another attempt; this time to make the flight from the Weddell Sea to the Ross Sea, because an earlier start was possible in that direction owing to earlier break-up of the pack ice about Graham Land. But the weather was altogether against us, first at Deception Island and later at Snow Hill Island on the east coast of the archipelago, where we found a suitable flying base. We made a start on January 3, 1935, but were soon driven back by bad weather. In the whole of that season, and we were there for 3 months, we had less than 12 hours of flying weather. Returning from Snow Hill Island, we were caught in the pack and got free with difficulty, and for the third attempt we chose a safer base, Dundee Island, some 80 miles north of Snow Hill, which we had marked on the return from the previous attempt. The *Wyatt Earp* reached Dundee Island again in November 1935 with Sir Hubert Wilkins and five others who had been on all three expeditions. For pilot on this flight I was fortunate in obtaining Mr. Herbert Hollick-Kenyon, who had obtained leave from Canadian Airways; he had much experience of flying in subarctic conditions.

At the summit of Dundee Island, about 500 feet above sea, there was an almost unlimited snowfield with an excellent take-off slightly downhill. Supplies and fuel were hauled up on sledges and personal equipment carried by the plane during test flights. The weather was favorable and we took off on November 21 in clear weather for what we hoped would be the main flight, but after about 600 miles our fuel gage clogged, so that we were forced to return, and landed after 10½ hours in the air. We had realized from our experience on the first two expeditions that the only way to fly in the Antarctic is to start in good weather, and, if it turns bad, to be prepared to land and await the return of better conditions. So this time we took no meteorologist on our base staff, feeling that it is impossible to forecast in the Antarctic.

Next day the machine was refueled and the engine tuned up again by the mechanics. The weather promised to remain clear, and Hollick-Kenyon and I were called at 02.00 on the 23d. (All dates and times are Greenwich Civil Time.) We ate a hearty breakfast and then dressed in heavy clothing, with snowshoes. We purposely made slow time walking the 5 miles to the plane, because we did not wish to get our clothing damp with perspiration before taking off. After 2 hours we reached the place where the *Polar Star* lay ready for flight. As Kenyon busied himself with last adjustments I had only one thought: "This time we must make it."

When we took off to the south at 08.04 on November 23, the weather was clear, the temperature −3° C., and the sea a turquoise blue which gave a marvelous reflection on the mountains. By 08.30, as we flew along the coast of Ross Island, we had climed to 6,400 feet and the temperature had dropped to −10° C. Weddell Sea was quite open for the first 300 miles—unusual in the Antarctic springtime. For 600 miles we flew along the eastern coast of the Antarctic Archipelago, until we came to the frozen channel which we identified as Stefansson Strait. It appears to be not more than 3 miles wide, much narrower than is shown on the map of the American Geographical Society, and we could not see far enough to determine whether it actually connected the Weddell and Bellingshausen Seas, or was merely a deep fjord, though we had risen to more than 13,000 feet.

So long as we had landmarks for checking the plane's ground speed and position, we made careful notes of dead reckoning, and found that our ground speed was lower than expected, but was 120 miles per hour or more. By 09.30 we noted that there was some wind and later that we were drifted too far to the east, and our course was altered to allow for this.

The low, black, conical peaks of Cape Eielson rose conspicuously on our left, and with keen curiosity we gazed ahead at the great mountain range to be crossed. Bold and rugged peaks, bare of snow, rose almost sheer to some 12,000 feet above sea level. Impressed with the thought of eternity and our insignificance, I named the new mountains the Eternity Range, and the three most prominent peaks on our right Faith, Hope, and Charity, because we had to have faith, and we hoped for charity in the midst of cold hospitality. They were in striking contrast with the flat low peaks of the Antarctic Archipelago which we had followed south, peaks which dwindled into low isolated nunataks as we neared Stefansson Strait. The range which we were now crossing was loosely formed, with none of the crowded topography of peaks and glacier-filled valleys with crevassed bottoms.

After 3 hours the mountains beneath us gave place to a vast polar ice plateau from which emerged a few nunataks, the last relics of the mountain chain just passed. We were flying at 10,000 feet, which was the average altitude of our flight. During the first hours of the flight we had constant two-way radio communication between the ship and the plane. But at 16.15 I logged: "Transmitter out of action. Only thing is to go on." We had traversed 1,000 miles and were yet 1,300 miles from the Bay of Whales. We sighted several isolated mountain peaks, but these soon faded out on our right about 16.20. Forty-five minutes later other peaks showed on the same skyline, and in another 25 minutes more mountains 120 to 140 miles away appeared on our left horizon, and also a few peaks to the right.

Sun sights taken at 16.53 and 18.54 gave a fix which appeared to show that we were more than 200 miles west off our course; as will be explained later the bubble sextant had got badly out of adjustment. At 17.00, when by estimation we had passed out of the Falkland Islands sector, I logged: "Long. 80° dropped American flag and named the land up to 120° west James W. Ellsworth Land. What a thrill!" One hour and forty-five minutes later we came abreast of a solitary little range about 25 miles away on our left, symmetrically formed, with a central pyramid rising to 13,000 feet. I named it Sentinel Range, and its central peak Mount Mary Louise Ulmer, after my wife.

Fifteen minutes later, and 100 miles distant on the southern horizon appeared a long, black, flat-topped range which extended visibly through at least 1° of latitude. This looked like the last of the mountains we were to see, for ahead lay only a vast plateau to the horizon. At 20.30 I noted: "No landmarks visible. Only a limitless expanse of white." At 20.45 Hollick-Kenyon passed me the following message: "I really have no idea where we are—but our courses carefully steered should put us close in," and it proved in the end that we had remained surprisingly close to our scheduled course, within 45 miles, though our speed had been much lower than expected. We had been in the air nearly 14 hours; visibility began to get poor, and we determined to land and take sights of the sun for our position, for we had no fuel to spare. We had no knowledge of what the surface might be like, and it was misty on the ground, but we landed safely at 21.55 on November 23, though we crumpled the fuselage in landing.

This was the first of our four landings during the crossing, and 12 of the 19 hours here were spent in taking observations to check the position of this our first camp, which we will call Camp I. After getting one position line, it was necessary to wait 2 or 3 hours to get another line crossing the first at an angle sufficient to give a reasonable intersection. I went out once to get exercise between the observations, but the monotony of the terrible expanse of endless white got on my nerves, so that I was glad to get back into the four walls of the tent. There are 24 hours of daylight in this region at this time of year, and that, too, wears on the nerves. The temperature was 15° below freezing. During our 19 hours here we strung up the antenna wires on the bamboo sledge poles, worked the sledging-set transmitter by hand, and kept on sending calls, both general and to the *Wyatt Earp*, but we got only one response during the 22 days of our journey across Antarctica, and that was: "We can't hear you." The dead reckoning position of the camp was latitude 80°28′ S., longitude 141°02′, but our ground speed had been much overestimated, for the position as determined by our observations was 80°20′ S., 104° W. And we had not then overcome the trouble with the sextant. When its index error was eventually discovered and the sights recomputed, it proved to be 79°15′ S., 102°35′ W. The snow on the high plateau was granular and packed so hard that the skis of the plane made little impression. The surface elevation was 6,400 feet, and the plateau extended with slight undulations in all directions.

The Pole lay 750 miles south, Dundee Island 1,550 miles behind us, the coast line of the continent several hundred miles to the north, and the Bay of Whales 750 miles ahead. It was here that I raised the American flag, and so far as that act would allow, claimed the sector between longitudes 80° to 120° W. for the United States, having already in my mind named it James W. Ellsworth Land after my father. That part of the plateau above 6,000 feet I called Hollick-Kenyon Plateau. We set up our balloon-silk tent and took repeated altitudes of the sun with the sextant.

After 19 hours at Camp I, we again took to the air at 17.00 on November 24 in calm weather, but looking thick ahead. We felt we must push on, for our chances of a successful crossing were decreased in proportion to the time we lost at any one place. We soon experienced low visibility, and at the end of a short half hour we were finally forced to land again, with a ground elevation of 6,000 feet. We were surprised at the ease with which we could land or take off on a hard surface. It required no more than 50 yards to rise from the snow when we left the first camp on November 24. This is all the more remarkable since we had no assisting wind, and since we were at an elevation of 6,400 feet above sea level.

At Camp II, we waited 3 days for good weather, trying strenuously and continually, but fortunately unsuccessfully, to fix our position. I say fortunately because the number of observations we made here were useful later in tracing the error of our sextant. After getting only a very rough approximation to our position, we took off in great uncertainty about the precise direction of Little America.

This was on November 27. After 90 miles, we landed in a fog, and at 02.30 a blizzard was upon us. On November 28, 29, and 30 we lay all day in our sleeping-bags with drift and gale reaching 50 miles per hour. By November 30 there were huge drifts around the plane, and the cockpits were full of snow. We were unable to get into communication with the *Wyatt Earp*, although on November 30 we got three time ticks from Buenos Aires. We were 600 miles from Little America and probably had not enough fuel left to get there. I consider this stay at Camp III as the low-water mark of our flight.

However, with our prospect appearing so dark, our situation was improving. At Camp III we luckily thought of the simple expedient of adjusting the bubble of our sextant on the snow horizon when the index read zero. This showed that the sextant had after the first observation developed an index error of 82 minutes of arc, and that it had been apparently constant. We reduced it to an uncertainty of about 4′, enabling us to fix our position and to set a direct course to Little America. Once the sextant was put in approximate adjustment, our navigation problem became a simple one. All observations, except the very first one, were corrected for the determined index error of 82′ and the positions reworked with impressive results.

The second observation, taken in the air at 18.54 on November 23, showed that the plane was behind schedule. The big discrepancy in the estimated air speed of 145 miles per hour and the actual ground speed is accounted for by several factors: (1) The substitution of skis for wheels causing an unexpectedly heavy drag; (2) a slightly crumpled fuselage which altered the streamline and thereby reduced the speed; (3) unexpectedly heavy head winds; (4) low temperatures which reduced the engine-power output; and (5) throttling down the engine to save fuel. During the whole midsection of our flight, from the time we left Eternity Range until we started on the downgrade to the Ross Barrier, the prevailing wind blew from the east and southeast. Only twice did we have a north wind, and then only for a few minutes. We never had a west wind. But these factors hardly account for the reduction of more than 25 percent in the speed of the *Polar Star*. The measured speed at the beginning of the flight when the plane was heavily laden, and the known speed of the plane on the last two legs, was relatively much higher, so that an extremely low ground speed of about 92 miles per hour was made on the first and most dangerous leg of the flight.

On December 1 we spent the whole day clearing snowdrifts from the plane, which was one solid block of snow. To crawl in among the controls with a teacup and clear away dry snow as fine as flour was the worst job of all. On December 3, we tried to start up the machine, but the magneto burned out. It looked as though we were 650 miles from the Bay of Whales with no hope of getting there. When the blizzard abated we were able to cut snowblocks to erect a shelter to the windward of our tent. For 8 days, until December

4, the storm held us prisoners in the camp. Our only excursions outside during the blizzard were to use the wireless three times daily and to fill our bucket with snow for water. Our food ration was 34 ounces a man each day, but we were not obliged to adhere to the allowance as we ate only twice a day. Even then we were never very hungry. In the morning we had a mug of oatmeal with chunks of bacon boiled in it, milk, sugar, and oat biscuit with butter. In the evening we had a mug of pemmican, oat biscuit, and butter. I thrive on this simple diet, just as in 1925 with Amundsen I never grew tired of our menu of hot chocolate morning and night, and pemmican at noon.

One morning we tried unsuccessfully to start the airplane motor after warming it for an hour. The situation seemed bad, for we were being buried deeper and deeper in the snow. We decided that we must get out of that hole irrespective of the weather ahead, and after 8 days in the blizzard camp we put the canvas hood over the motor and placed the fire pot inside for 45 minutes, as we always did before starting. Then we cranked the engine. After a couple of weak turns the propeller would stop with a choke. Kenyon connected the stronger radio battery to the starter and had the propeller going in no time. With the plane unloaded we pulled out of the drift, loaded up again, and at 19.20 on December 4 we took off into a sky which was anything but promising. But we had not been flying long before the horizon became clear and the sky took on a beautiful golden glow.

At 23:10 we came down to get a sight, which made Camp IV in 79°29′ S., 153°27′ W. It was a beautiful calm night, the boundless snow fields sparkling like diamonds. There was no wind, we had left the high plateau, and were only 145 miles from the Bay of Whales. Once more it was good to be alive. We were now on territory explored by Byrd and all we wanted was to get to our destination.

At 09.00 on December 5 we took off and at 09.50 reached the north end of Roosevelt Island, only 16 miles south of the Bay of Whales, but we did not know this at the time. From the air we saw the ice-free waters of Ross Sea, the goal of my 4 years of endeavor. At 10.05 the *Polar Star* slackened her speed and came gently to the snow, her 466 gallons of gasoline completely exhausted. Here we made Camp V.

On December 6, we dug trenches to settle the skis in, waiting to walk to Little America. On December 7, the southeast wind continued, with snow squalls and temperature round about freezing-point. On December 8, standing on the wing of the plane and looking northwest, we saw among a lot of irregular ice hummocks, that might be snow-covered buildings, what Kenyon thought was a wind-generating tower. Was it Little America? We thought we would trek over on our snowshoes, but after a 2 hour walk we appeared to be no nearer and returned to the plane.

On December 9, we packed our hand sledge with 10 days' ration and started off, leaving our tent with the plane, and expecting to find shelter in the huts. We traveled 9 miles of heavy hauling in the soft snow, and as we neared the tower we saw that it was only an ice pinnacle. Being without tent or sextant to fix where we were we had to leave the sledge and return to the plane for both; rested an hour, and got back to the sledge at 03.00 on December 10. We made Camp VI here, and after 7 hours' sleep took sights and fixed its position in 78°38′ S., 163°20′ W. about 12 miles south of the head of the Bay of Whales. The weather for 2 days had been perfect, with no wind, the sun shining out of a cloudless sky and the temperature above freezing.

On December 11, we traveled 10 or 11 miles, sledging by low sun, and had one bad pull over a crevasse. It was weary work, and it seemed as though we must be going in the wrong direction, for the never-ending expanse stretched on forever. The low night sun cast a dull glow over the ice fields without warmth, although the sky was cloudless. Suddenly I told Kenyon I could see a line of blue water on the horizon. It was the Bay of Whales, and we had been traveling much too far west.

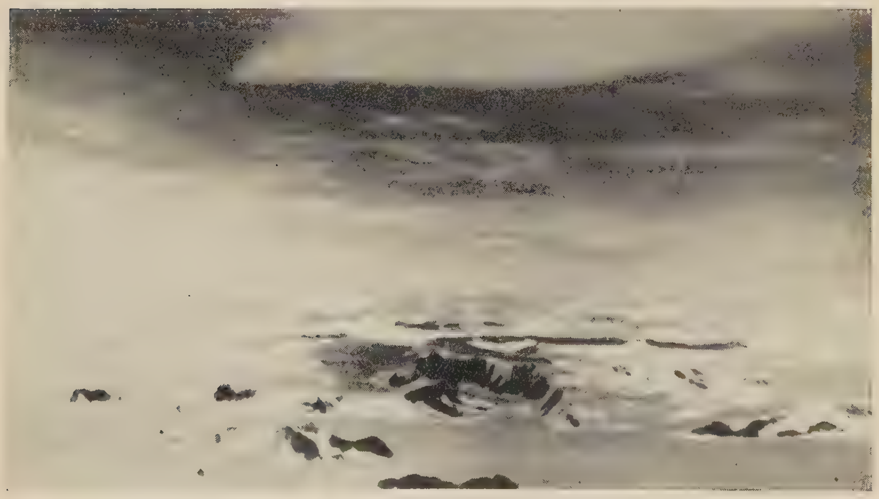
On December 12, however, although we marched 12 miles, we were unable to find the water which we had seen the day before. On December 13, traveling entirely by compass as before, in misty weather with snow flurries, we made another 10 miles. We approached a ridge and hoped to get an extended view. Topping it, we looked straight down into salt water. We had heard the lapping of the waves and thought it was the wind but it really was the sea at last.

On December 14, we reconnoitered and in the evening took a sight, to find we had traveled about 10 miles too far north, and must go back south. We judged that we were at the mouth of the Bay of Whales. On December 15, we traveled 15 miles and came, at "Ver-sur-mer", Byrd's unloading place, upon two tractors half-buried in snow. This gave us our position, so we dragged on up the east side of the bay, topped a rise, and looked down upon the most desolate remains of past habitation that I have ever witnessed: only a lot of masts and the stove pipes of buildings sticking out of the snow. We broke though a glass skylight, and were able to let ourselves down into what proved to be the radio shack.

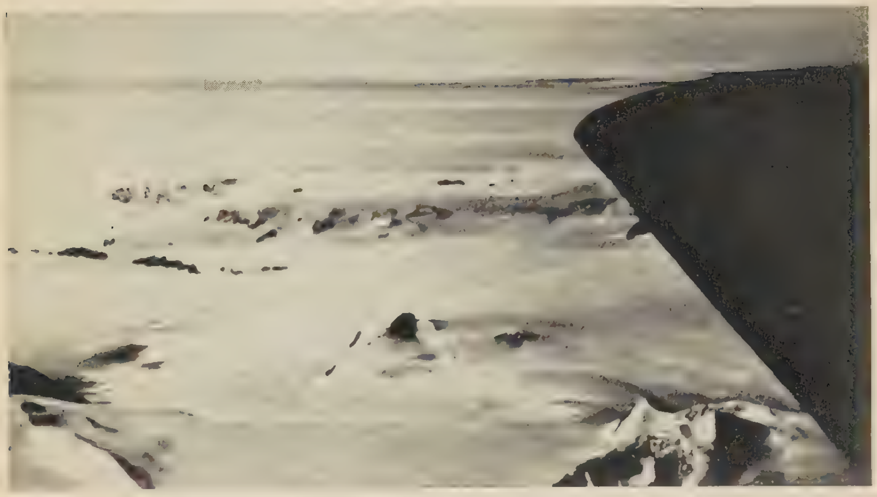
On December 16 we dug a tunnel and made steps down to the door of our shack. We found coal, gasoline, and some welcome stores. We cleaned up everything, and settled down to a routine to await the arrival of the *Wyatt Earp*. Every day I walked 6 miles down to the tractors where we had put up our tent, with two yellow streamers and a note that we were at Little America, so that the *Wyatt Earp* could know where we were.

On January 15, a month after we arrived at Little America, I was awakened at 22.00 to see Kenyon standing over me with a note in his hand. He had heard the roar of a motor overhead, although our dugout home was 15 feet beneath the snow, and had crawled up to the surface in time to see a parachute descending through the fog which had enveloped us for 2 weeks. The parcel contained food, and the note was from Captain Hill, commanding the R. R. S. *Discovery II*. Within 10 days after the failure of our radio the Commonwealth of Australia had sent a relief expedition, and had been seconded in this by the Governments of the United Kingdom and New Zealand. As I was laid up with an infected foot, Kenyon started off alone to meet our visitors; but I could sleep no more that night, and started out in snowshoes to learn what was up. A mile from camp I saw through the fog, which magnified frightfully in these regions, what appeared to be a whole army of men marching toward me; in reality there were six of them. We packed the sledge and started for the ship, where I was received with open arms, and learned that my own ship had been delayed by the pack ice in the Ross Sea. Three days later a radio message told us that the *Wyatt Earp* was approaching the bay, and very soon the staunch little craft loomed up in the fog. While my party was loading the *Polar Star* on the *Wyatt Earp* I went on the *Discovery II* to Australia, where I was for 12 days the guest of the Government.

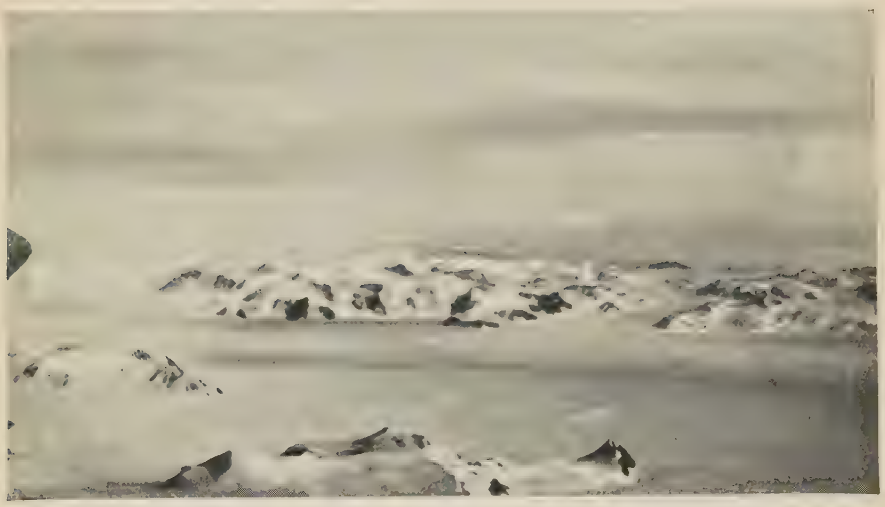
1. NOVEMBER 21, 1935, 12:19. THE ETERNITY RANGE AS SEEN ON THE FIRST FLIGHT.



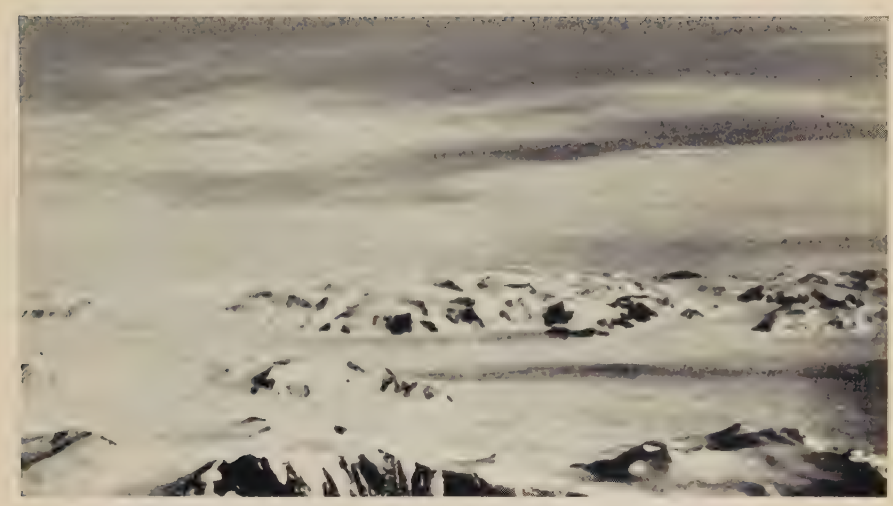
2. NOVEMBER 23, 1935, 12:25. EAST COAST OF GRAHAM LAND AS SEEN TO RIGHT.



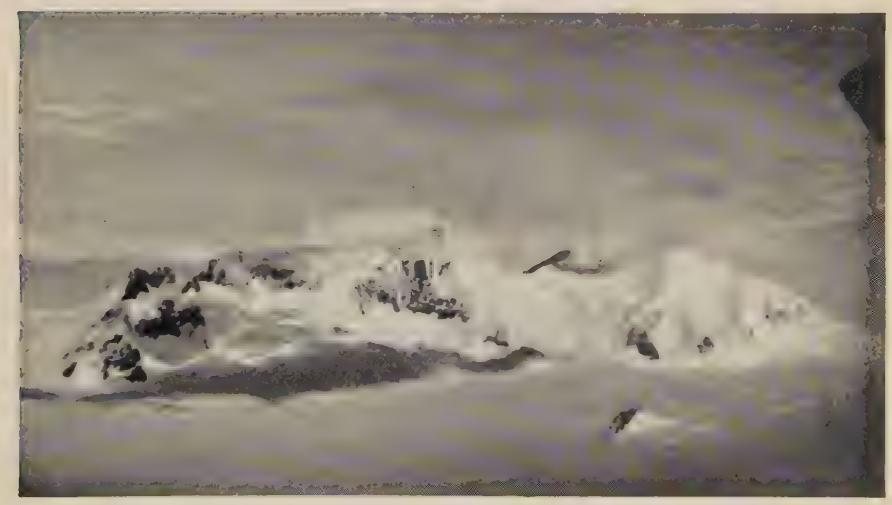
1. NOVEMBER 23, 1935, 12:38. LEFT TOWARD CAPE EIELSON AND BEGINNING OF ETERNITY RANGE



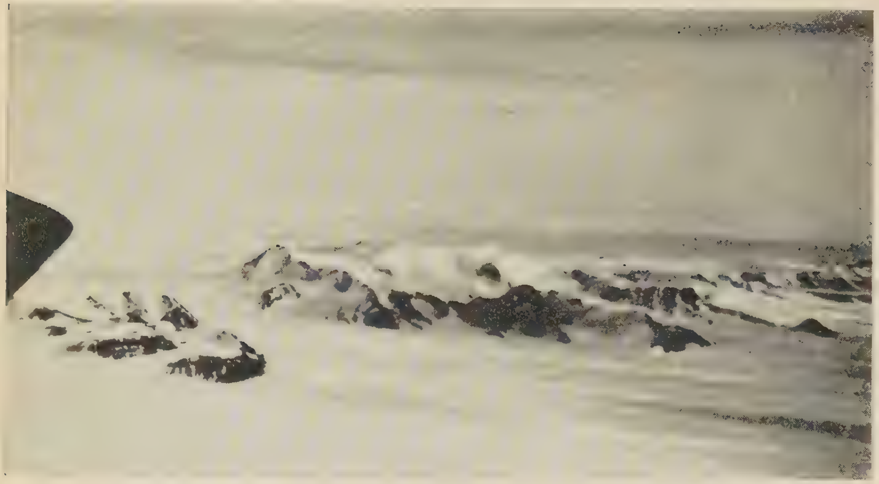
2. NOVEMBER 23, 1935, 12:41. TO RIGHT, ACROSS ENTRANCE TO STEFANSSON STRAIT.



1. NOVEMBER 23, 1935, 12:45. THE SAME A LITTLE LATER, LOOKING FARTHER WEST UP THE STRAIT OR VALLEY.

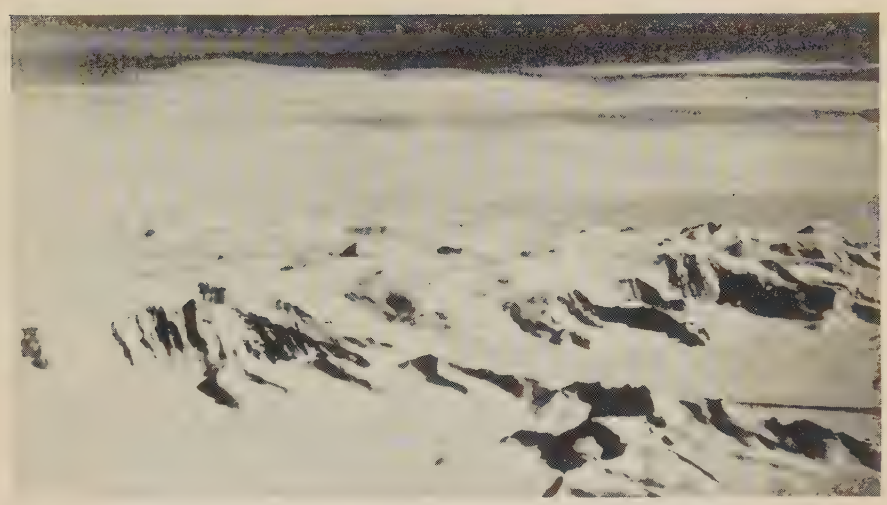


2. PROBABLY THE OPPOSITE FACE OF THE FEATURES IN MIDDLE DISTANCE OF FIGURE 1, ABOVE, TAKEN ON FLIGHT NOVEMBER 21.

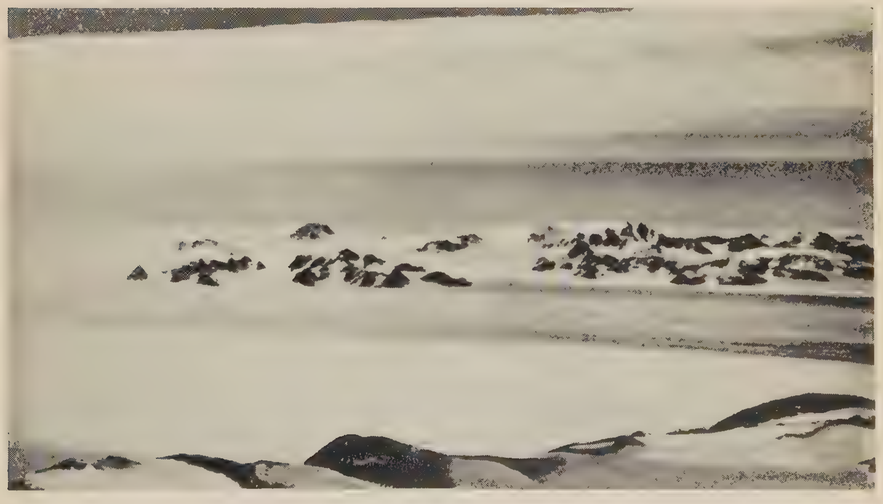


1. NOVEMBER 23, 1935, 14:37. TO RIGHT, OVER UNNAMED MOUNTAINS.

2. NOVEMBER 23, 1935, 14:45. CONTINUATION OF MOUNTAINS TO RIGHT, OVERLAPPING FIGURE 1, ABOVE.

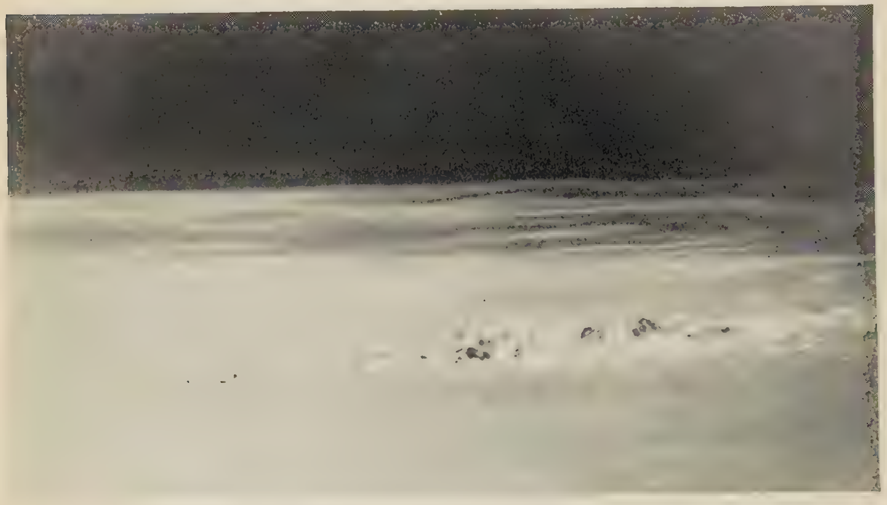


1. NOVEMBER 23, 1935, 14:53. CONTINUATION OF MOUNTAINS TO RIGHT, OVERLAPPING FIGURE 2, PLATE 4.



2. NOVEMBER 23, 1935, 15:00. CONTINUATION OF UNNAMED RANGE TO THE LEFT.

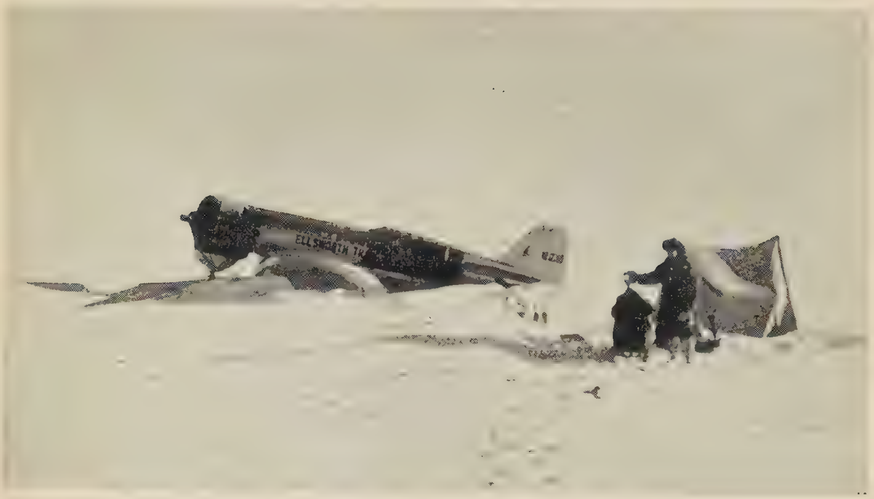
1. November 23, 1935, 15:05. Continuation to Left Overlapping Figure 2, Plate 5.



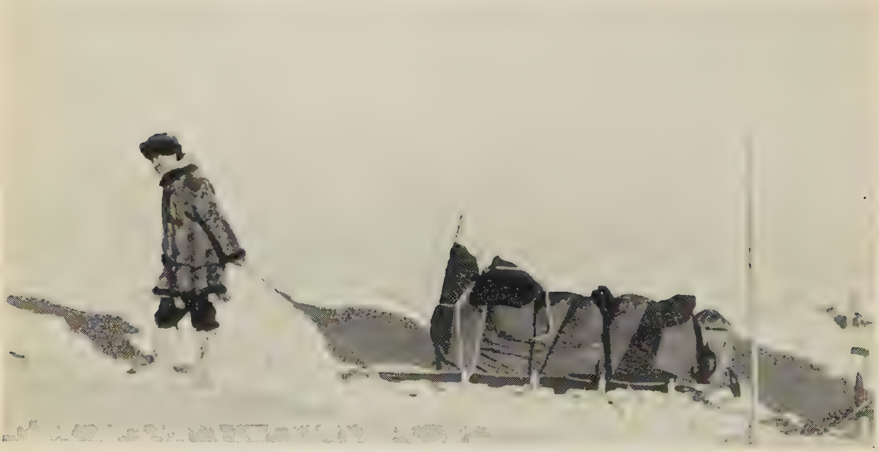
2. November 23, 1935, 19:30. The Sentinel Range to the Left.

1. NOVEMBER 24, 1935, 17:29. THE AIRPLANE IN CAMP II.

2. THE AIRPLANE SNOWED UP IN CAMP III.



1. SLEDGE PACKED FOR DEPARTURE FROM CAMP V (DECEMBER 9).



2. DECEMBER 9, 1935. START FOR LITTLE AMERICA.

1. LINCOLN ELLSWORTH ON ARRIVAL AT LITTLE AMERICA. DECEMBER 15.

2. HOLLICK-KENYON AT LITTLE AMERCIA.

MOVING PHOTOMICROGRAPHY [1]

By W. N. Kazeeff

[With 12 plates]

For a long time the microscope served the purpose of observing small animals, tissues, and cells without special preparation. The desire to see more and to see better finally led the histologists to invent all kinds of techniques of fixation and coloration. Then scientists returned to the method of examination in vivo as more certain. The perfection of optical instruments (homogeneous immersion, black background, etc.), the progress of means for penetration of the cells, such as the culture of the tissues in vitro and micromanipulation, permits the experimenter of today to observe the reactions of the cells during their life activities: Their direct reactions, their movements, their divisions, and their difficulties. Moving photomicrography lends to these new researches its clearness and precision of analysis and also the possibility of making visible all the movements of the cell even when they may be too slow or too brief for our eyes to see. In other words, it raises microscopic space and time to our own scale.

If moving pictures are the splendid achievement of the Lumiére brothers, moving photomicrographs are that of another Frenchman, Dr. J. Comandon. The actual realization is the termination of painstaking research of more than 25 years. In these past 15 years Dr. Comandon has found a valuable collaborator in the person of De Fonbrune, who among other important discoveries in the domain of moving photomicrography has invented the micromanipulator described in No. 2967 of La Nature.

Little by little, the microscope and the apparatus for taking pictures have been adapted to each other to result finally in the present apparatus, a veritable little factory of very high precision.

The apparatus conceived by Dr. Comandon (pl. 1) is composed of four parts made as independent of each other as possible to prevent vibrations communicating between each part and in particular to the microscope. The different parts are as follows: (1) A large table on which is placed the Zeiss optical bench for photomicrography. It supports the source of illumination *a*, the condensers, and the condensing lenses; (2) the microscope *c* placed on a socket resting on a platform free of vibrations; (3) a heavy metal structure that supports the moving picture apparatus *f*; and (4) a lateral steel table on which are fixed the movable parts and the shutter *d* which periodically cuts off the light ray between the lamp and the microscope. An electric motor *e* placed under this table on the floor activates the different movements.

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[1] Translated by permission from La Nature, No. 2971, Feb. 15, 1936, and No. 2975, Apr. 15, 1936.

These four parts and the electric motor have their bases sealed into a concrete block sunk into the floor. The vibrations produced by the functioning of the apparatus as well as the vibrations of the street and building are easily reduced by this large mass; no vibrations whatever are transmitted to the optical part of the apparatus.

The large Zeiss photographic microscope *c* with its different optical combinations of objectives and oculars is generally used for the work.

The sources of illumination differ according to the photographs taken; they are: An arc lamp with continuous current of 20 amperes, or an incandescent lamp (automobile head light of 100 candlepower, 12 volts), or the Koehler apparatus—a spark between cadmium electrodes, the prism and optics of quartz for making moving pictures in ultraviolet light.

The upper part of the table, supporting the lamp and the optical bench, is placed on a slide screwed into this heavy structure. It can thus be shifted horizontally, parallel to the optical bench, especially when it is desirable to photograph preparations in a vertical position; the microscope tube is thus inclined about 90° horizontally to the axis of the light ray projected by the lamp. A prism with total reflection, fixed to the ocular, reflects the light ray forming the image upward vertically to the center of the window framing the film.

Generally, the photographs were taken by means of the vertical microscope as the photographs show in plates 1 and 2. The light ray falls on the center of the mirror of the microscope, then is reflected perpendicularly according to the optical axis of the microscope, and terminates as in the preceding at the window of the apparatus.

The apparatus for taking the moving pictures *f* is a G. V. Debrie, modified according to the directions of Dr. Comandon. This remarkable apparatus of great speed (which was created by Labrély) permits taking more than 250 views per second. At this speed, the system of catches which pulls the film causes the substitution of one image after another in less than one five-hundredth of a second. Such great speeds are used in moving photomicrographs only for analyzing very rapid movements; at lower speeds, this apparatus has the great advantage of increasing the length of time of pose for the usual speeds of motion pictures.

By a slight modification of the G. V., a period of pose is obtained which is five times longer than the period of juggling or closing, and this is for a speed which can exceed 32 images per second (the normal speed being 16 images per second). This result is attained by means of a cog that raises the catches and prevents their taking up the perforations of the film for a duration that would correspond to three images if these catches were free to work. At the moment which would correspond to the end of the pose of the fourth image, the catches are lowered and drawn along the film the length of an image, at a speed three times greater than that of a normal apparatus for the same time. The time of pose is thus twice as long as in the regular apparatus. This is an important improvement in the photographic utilization of time and light flux. It permits making moving pictures of delicate subjects that are sensitive to the light, by utilizing a weak light source while keeping the rapid time that is necessitated by the speed of their movements.

An accessory arrangement provides for a record of the time on each image, which shows the exact speed of the photograph taken. This record is obtained with the aid of a very small objective placed on the left side of the apparatus which by means of a prism in a circle of 3 millimeters diameter situated in an upper corner of the film, gives the image of a chronometer with a transparent dial *g*, placed at a determined distance in front of the objective and lighted by a little incandescent lamp *h*. Each image records thus the minute and even the fraction of second of the pose. By substituting a thermometer or galvanometer needle in the chronometer, there can also be registered the temperature, the direction of an electric current, or any of the other conditions of the experiment.

The moving-picture apparatus fixed solidly on a slide can be raised or lowered along the cast-iron arm with a minimum of effort by means of a regulating wheel *i*. When it is raised to the maximum, the experimenter can look into the microscope and observe the preparation directly. At the moment of photographing, the apparatus is placed at the desired distance for a determined enlargement indicated by an index which slides on a metric rule *j* fastened to the iron structure. The junction of the light between the microscope and the film is obtained by means of a bellows with an extensible draft.

An important improvement applied by Dr. Comandon is a telescope system *k* and a prism that not only makes possible direct focus upon the film but also continuous observation of this while photographing. The moving objects can in this manner be maintained in the field by adjustment of the microscope screw and observation can be continued without interruption of the microscopic preparation reflected on the unexposed film, in the same manner that a photograph shows the object or the subject to the photographer on a ground glass placed in focus.

The apparatus is run by an electric motor of 0.7 horsepower sealed directly into the concrete masonry. Normally it gives 1,500 revolutions per minute, but this speed can be reduced one-half by means of a rheostat.

The movement of the motor is transmitted by a belt to a horizontal intermediate shaft supporting several pulleys. By means of this and another belt, the rotation is communicated to another horizontal shaft either directly or by means of speed reducers. This shaft operates the camera apparatus and shutter; the operation is thus maintained perfectly synchronous with that of the moving-picture apparatus. The speed reducers are fixed very conveniently on the slot of the steel table; they can be clamped one following the other so that the first one receiving the movement by a belt of the intermediate shaft transmits it, reduced in speed to a second reducer, then if necessary to a third. Each reducer is characterized by its coefficient of reduction and on combining these coefficients, the varied speeds can be obtained.

The shutter *d* is a balanced sector that cuts the light ray as near as possible to the microscope. In this manner, the microscopic preparation is neither lighted nor heated during the time of closing, thus taking care of the delicate micro-organisms.

The microscope can be enclosed in an electrically heated chamber *n*, and in this way the preparation can be maintained at a constant favorable temperature just as in a bacteriological chamber. The front side of this chamber is of glass which permits passage of light rays. The ocular emerges from the upper part of the chamber, and at a convenient place on the side are knobs for regulating the focus and the movements of the mirror (pl. 2).

To prevent a loss of several meters of film, since the apparatus when started requires a certain time for stopping when the electric current is cut, Dr. Comandon has added a brake to the shaft of the motor.

Finally, a special operating part, invented by Dr. Comandon and De Fonbrune, controlled by a chronometer, permits setting the apparatus automatically into movement, stopping it, and starting it up again at the end of a desired time. In this fashion the photographs can be made automatically at any moment fixed in advance by the operator and also during his absence. The time recorded on each image (in the upper corner of the film) shows the exact time at which any modification or movement registered on the film is produced.

Another problem, not less complicated, consists of guarding in good condition the life of the organisms and cells that are being photographed. Two accessory parts can be utilized for this purpose:

The improved moist chamber (of Ranvier) and the oil chamber. The improved moist chamber (fig. 1) consists of a glass slide on which is attached with sealing wax a flat glass ring about 15 millimeters in interior diameter and 1 millimeter thick. This ring has an opening 2 to 3 millimeters wide. It is covered with a cover glass that is sealed to the crown by means of a thin layer of vaseline. The medium and the objects to be observed are introduced through the lateral opening of the ring by means of a fine pipette. When the pipette has been removed, the lateral opening is closed up with a stopper of vaseline.

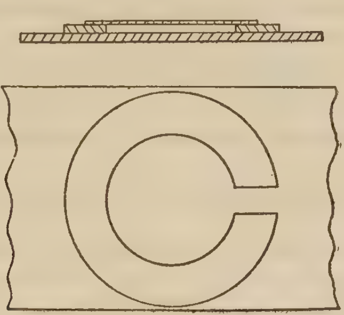

FIGURE 1.—Moist chamber.

The provision of enclosed air in this moist chamber is generally sufficient even to satisfy the need of larvae during their hatching. If necessary, the air and the medium can be renewed through the same lateral opening.

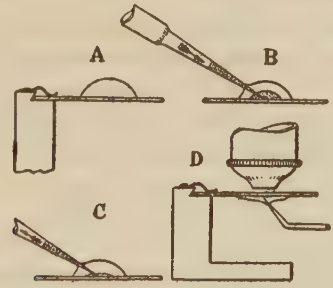

FIGURE 2.—Oil chamber.

The oil chamber (fig. 2) consists of a large drop of oil of vaseline placed on a cover slip held horizontally by means of a little support placed under the microscope (figs. 2–A and D). The center of the drop of oil just to the point of contact with the glass is pierced by the point of a fine pipette containing the medium and the living organisms. The pipette is connected to the mouth of the operator with rubber tubing. By lightly blowing into the tubing, the aqueous liquid is made to leave the pipette and spread out on the glass under the oil (fig. 2–B). The thickness of the layer is then regulated by inhaling the excess of the liquid until the cells are lightly compressed between the cover slip and the surface of the oil (fig. 2–C). Certain motile organisms, such as rotifers, larvae, or ciliated Infusoria can thus be rendered immovable. In the same manner, excess of oil can be removed. The aqueous liquid, thanks to its adherence to the glass, forms a thin layer under the oil.

Owing to all these improvements, Dr. Comandon has made wonderful moving pictures with the microscope. Our readers can readily appreciate this by examining the few views reproduced here, although they are inanimate on the pages of our article. The films on the black background are made by using the ultramicroscope lighted by an electric arc.

REPRODUCTION OF AMOEBAE

When numerous unicellular organisms find themselves in unfavorable conditions, they undergo a change of form. Certain bacteria become deformed and go into involution; certain protozoa encyst. When the medium returns to a favorable state, they come out of the cysts and resume their customary shapes. Plate 3, figure 1, represents five amoebae which have been encysted for several weeks. Their protoplasm is in a state of complete repose. At their right can be seen a wandering amoeba. The diameter of these cysts is from 0.013 to 0.016 millimeter.

Figure 2, which follows, taken at 4 o'clock, shows a cyst on the point of breaking. The projection shows the very lifelike movements of the protoplasm of the amoeba in its cyst and a contractile vacuole has appeared. At 4:36, the amoeba tears open the cyst toward the right (fig. 3), and at 5:32 the young amoeba escapes through this narrow opening (fig. 4).

Figure 5 shows a young amoeba which is beginning to take nourishment; it has already collected several bacteria with the posterior part of its body. Finally, figure 6 represents the most usual mode of reproduction of the amoebae—simple division.

DIVISION OF TRYPANOSOMES

The trypanosomes, among which are found species pathogenic to man, such as *Trypanosoma gambiense*, which is the agent of sleeping sickness, are Protozoa. They generally multiply by longitudinal division as shown in plate 4, where trypanosomes are shown undulating among the spherical red blood corpuscles in the blood.

THE LIFE OF AMOEBAE

Plate 5, figure 1, shows an amoeba taking nourishment which consists of an alga. It is 19 minutes 50 seconds past 11 o'clock; a pseudopodium of the amoeba is on the point of engulfing the extremity of an oscillating alga. The pseudopodium progresses slowly about the algal filament as shown in figure 2, taken 55 seconds later. It finally withdraws, carrying with it the algal filament which penetrates a small distance into its protoplasm (fig. 3, taken at 11:22). It is by similar movements repeated many times that the amoeba absorbs the entire filament.

Certain amoebae are also nourished by the protoplasm of cells of molds. In plate 6, figure 1, there are shown two amoebae braced against the same plant cell and attacking the cellulose membrane; the time is 11:25. At 11:28, the amoeba on the right has pierced the wall and absorbed the cell contents which pass into the amoeba and form a large vacuole. At the same time, the other amoeba detaches itself from the support and moves away (fig. 2).

KARYOKINESIS

The following pictures were taken of the red blood corpuscles in the mother cells of the Triton, the diameter of which is about 0.025 millimeter. The nucleus, which is very large, occupies almost the entire cell, and like the cytoplasm of the rest of the cell, it is relatively opaque. Plate 7, figure 1, taken at 7:36, shows a cell that is ready to divide. The protoplasm is animated by very slow movements, difficult to distinguish by direct examination, but clearly visible in the projection because of the enlargement (about 50,000 times) and the acceleration of the movements, the speed being multiplied, according to the case, by 16, 48, 112, and even 480.

At this early stage, there may be observed a rotation of the nucleus in the plane of the preparation. This rotation may be, in one case, 360° in 6 minutes, in another case, about 225° in 23 minutes, in a third case, about 180° in 27 minutes. Probably this rotation results from the efforts of the nucleus to embed itself into the cytoplasm before division.

There then ensues the gradual formation of the nuclear spireme; the disappearance of the nuclear membrane is very rapid (fig. 2 at 7:45). At this moment, the deformations at the periphery of the cell cease abruptly. The spireme becomes loosened and forms strands which are generally placed at the periphery of the cell and in the plane of the preparation when the cell is lightly pressed with a cover slip. The transversal division of the threads of the spireme gives rise to the chromosomes which begin to form the equatorial plate (fig. 3 at 8:27). In those chromosomes situated in the focal plane, the phases of the longitudinal division can be followed, then the migration of the new elements toward the poles of the diaster (fig. 4 at 8:35). The chromosomes then group to form two daughter nuclei (fig. 5 at 8:42). At the moment of the constriction of the protoplasm, there can be distinguished fibers that run perpendicularly to the plane of segmentation; these are the connecting filaments of the spindle (fig. 6 at 8:51).

While the nuclei of the two daughter cells are being constructed, the characteristic checkerboard arrangement taken by the chromatic network may be observed, and there is also noticeable a progressive darkening appearance of the cytoplasm caused by the hemoglobin (fig. 7 at 9 o'clock).

The daughter cells directly after cell division takes place present a very striking lobular appearance which progressively changes until they return to their definite forms (fig. 8 at 11 o'clock). There can be seen in the upper right of this latest picture a leucocyte traversing the photographic field.

HAEMOLYSIS OF THE BLOOD

The photomicrographs of the haemolysis of the blood give a basis for judgment of the hypotheses and theories made regarding the structure of the red blood corpuscles, which have been contradictory up to this time because of the imperfections of the means of ordinary investigations, such as the microscope and the ultramicroscope.

It should be remembered that the diameter of the human red blood corpuscle is about 0.0075 millimeter. The red blood corpuscles of several mammals when in contact with hypotonic solution first become spherical, then undergo a slight shock and gradually become pale, showing a contour that is scarcely visible (pl. 8, fig. 1).

The human red blood corpuscles in an acidulated solution (1/1,000 N hydrochloric acid, for example) swell up, then burst; there may then be observed a white turbidity that starts at one point of the periphery near the exterior, progresses, and soon forms a circular region that results in the flocculence of the proteins expelled from the globule (pl. 8, fig. 3).

With the action of bile, the nucleated red blood corpuscles of the Triton seem to soften, changing into a cylindrical or shuttlelike form; then their walls disintegrate, commencing at a point on the periphery, and this destruction proceeds very rapidly in all directions. It is a sort of stripping of the blood corpuscle, the contents of which are then dispersed. As to the human red blood corpuscles, the modification of the membrane and the dispersal of the globular contents, in the presence of the bile, take place so rapidly that there seems to be a veritable explosion (pl. 9). In the red blood corpuscles of the batrachians there may often be observed animated particles with Brownian movement that are freely displaced.

The contents of the red blood corpuscle then seem to be liquid. If there is a stroma in the interior, it must be composed of a few and very fine filaments which are invisible even in the ultramicroscope.

After haemolysis no stroma can be detected, and observations disagree regarding its presence. Thus in the preparation of the blood of the hen containing *Spirochaeta gallinarum*, or blood of the rat infected with *Spirochaeta duttoni*, the colorless, haemolized globules frequently contain perfectly motile Spirochaetes which seem to be caught in a trap (pl. 8, fig. 2) and which are unable to find the opening at which they penetrated. This indicates that there was a membrane at the time, and an opening, and that the stroma must be very loose if it does exist.

As may be judged from these few pictures, Dr. Comandon's films are extremely clever. They have excited the enthusiasm of scholars in the congresses and scientific societies where they have been presented. They prove that moving pictures can add new and precise observations to biological studies and that they can furnish irrefutable records, the analysis of which furthers research, as well as projections which facilitate instruction.

THE MEANS OF DEFENSE OF THE ORGANISM [2]

When an infectious disease is raging, certain individuals perish, others become sick and then recover, while still others are not attacked by the disease. The resistance to infection is designated by the term immunity. The mechanics of immunity are included among the most complex problems of research studied by biologists.

PHAGOCYTOSIS

Metchnikoff, a student of Pasteur, made known in 1882 one of the most active means for the defense of the organism against pathogenic agents—phagocytosis. While observing the nutritional process of amoebae, this scholar noticed that these very simple unicellular organisms on arriving in contact with a food particle emit pseudopodia that surround it and, after enclosing it, engulf it. A vacuole forms about the particle thus ingested; a true digestion proceeds; at the end of a variable period of time, according to the nature of the particle, it disappears. A large number of amoebae feed on bacteria (pl. 10, figs. 1–4). The same process is observed in other Protozoa.

But our own organism possesses white globules, called leucocytes, which, by their morphological characters, present analogies with certain nonpathogenic amoebae. In the healthy human organism, there are 5,500,000 red blood corpuscles and 6,000 to 8,000 leucocytes to the cubic millimeter.

While observing the behavior of the leucocytes in the presence of microbes introduced into the blood stream, Metchnikoff found that, like amoebae, the leucocytes emitted pseudopodia, engulfed the microbes, and digested them (pl. 11, figs. 1–3). He therefore gave them the name of *phagocytes* and called the phenomenon which he had just discovered *phagocytosis.*

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[2] Editor's Note.—The following pages, under the general heading "The means of defense of the organism," which formed a separate article by Kazeeff in La Nature, No. 2975, April 15, 1936, are here reprinted by permission to show the type of research that is aided by the new development of moving photomicrography and its great importance to human welfare.

The phagocytes are endowed with motility and sensitiveness; they direct themselves with certainty to the focus of the microbes. Up to this time, science has not been able to solve the mystery of how the phagocytes which are far from the point of introduction of the microbes are informed of their arrival. All that is known, is that the phagocytes move about (they traverse 2 mm in an hour by means of their amoeboid movements, according to the moving photomicrographic readings), and they can go out from the blood capillaries (diapedesis) to slide between stationary cells, in their effort to reach the point of infection.

Two categories of phagocytes are described: The smaller, or *microphages*, and the more voluminous ones, *macrophages.* It is the microphages especially that rush to the attack of invading micrboes and absorb them. The macrophages intervene in the combat as the rearguard of the microphages; when one of the latter succumbs without having digested the absorbed microbes, the macrophage speedily ingests the microphage crammed with microbian elements.

Almost immediately after the penetration of bacteria into a living organism, the microphages rush to the point of infection (pl. 12, fig. 1) and commence to engulf the intruders. A true battle takes place (fig. 2). The reinforcements of phagocytes continue to congregate, and their number generally attains its maximum after 10 to 24 hours (fig. 3). The macrophages which arise in the spleen, the lymphatic organs, and even the connective tissues arrive later, after 9 to 14 hours; they engulf the damaged cells and the microphages that have succumbed. A single macrophage is capable of absorbing from 2 to 10 microphages crammed full of microbes. A polymorphonuclear leucocyte (microphage) itself can absorb as many as 20 microbian spores.

The attacking microbes on their part attempt resistance. Certain ones, such as the tetanus bacillus, secrete a toxin that removes or destroys the phagocytes; others, by their prodigious multiplication overmeasure the losses undergone; those which are armored with a glutinous capsule (the pneumococcus and the tetrads, for example) or waxlike capsule (*B. tuberculosis*), or those which have time to form spores (anthrax bacteria) resist the phagocyte aggression. They produce new generations of microbes among the phagocytes which are already enfeebled and thus infection spreads.

The phagocytic defense is particularly active at the tonsil level, because of the mucus of the digestive tube and the mucous secretions of the digestive system, at the weakest points which are in contact with the exterior environment.

It should be noted that there also exist in several organs fixed elements (nonmotile cells) such as the Kupffer cells of the liver and the reticulocytes which are capable of destroying bacteria by engulfing them in the same fashion as do the phagocytes.

To Metchnikoff belongs the great merit of bringing to light the role of the phagocytes in the natural defense of the organism, but contrary to his opinion, this means of defense is not the only one. Its interpretation, which is too exclusive, raised numerous contradictions, especially in Germany. It caused a true scientific war of 30 years. While Metchnikoff and his pupils insisted that the principal factor of immunity is phagocytosis which engulfs the microbes and digests them, Baumgarten, Ziegler, Ehrlich, Behring, Pfeiffer, and others insisted that the principal factor of immunity rests in the bactericidal action of the humors and the blood of the organism (the humoral theory).

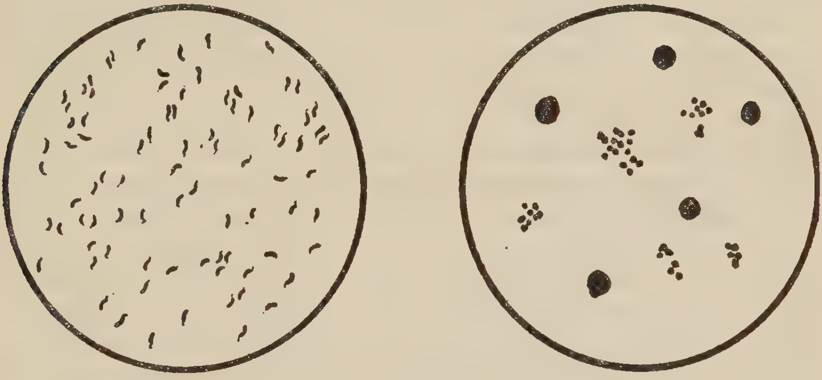


FIGURE 3.—The Pfeiffer phenomenon. At left, motile cholera vibrios in the peritoneal exudation of a young guinea pig; at right, agglutination and granulation of the vibrios in the exudation of an immunized guinea pig.

HUMORAL DEFENSE

Pfeiffer contributed by the following demonstrations the first experimental arguments supporting the humoral theory.

If the peritoneal exudation of a guinea pig is collected a half hour after an emulsion of cholera vibrios have been injected into its peritoneum, these vibrios present their usual appearance; they are motile and independent of each other. If a similar operation is made on a guinea pig which some time before has received a nonmortal dose of the same cholera vibrios, the vibrios become agglutinated, immobilized, having lost their form and present a granular aspect. It is evident that the blood serum of the organism immunized (in this case probably vaccinated or artificially immunized) against the cholera bacillus has acquired the power to destroy the microbes of this infection. This is the classical phenomenon of bacteriolysis (fig. 3).

Buchner, pursuing these studies, discovered natural haemolysis. If some red blood corpuscles of the sheep are introduced into serum of a rabbit, they are not dissolved; they are deposited little by little in the bottom of the tube; the liquid floating on the surface becomes clear and colorless. But if these same red blood corpuscles of the sheep are introduced into dog serum, they do not fall to the bottom of the tube; they are destroyed, and the liquid becomes uniformly red and translucent. Buchner attributed this haemolysis to a normal soluble principle named *alexin* (Buchner) or *complement* (Ehrlich).

Bordet has provoked artificially in the blood of the rabbit the formation of a haemolytic serum capable of dissolving the red blood corpuscles of the sheep. Having made four injections of red blood corpuscles of sheep into a rabbit, separated by intervals of 8 days, he determined that, 5 days after the last injection, the rabbit serum had acquired the power of haemolysis of the corpuscles of the sheep. Bordet then demonstrated that haemolysis is specific. For example, the serum of a rabbit immunized with the corpuscles of a sheep dissolves only the corpuscles of the sheep; the serum of a rabbit immunized with the corpuscles of the horse dissolves only the corpuscles of the horse, etc.

These experiments show that there can be created artificially a specific defense of the organism, that is to say, directed not only against the bacteria but even against an alien cell. Bordet has demonstrated also that haemolysis results from the combined action of two substances which he calls *alexin* and *sensibilisatrice* or *amboceptor.* While alexin is fragile and destroyed by heating at 55°, the sensibilisatrice is destroyed only by heating at 60°–65°. The first-named preexists in the normal animal; the second, specific, is lacking in the normal animal. It originates in the organism into which alien cells have been introduced.

Alexin, while being in principle able to destroy an alien cell, is incapable of filling this rule by itself alone, because it does not have the power to do so. The sensibilisatrice plays the role of intermediary, of mordant; it fixes itself on the alien cell and permits the alexin to exercise its own destructive action. Alexin is a normal defensive principle that is found in the blood of men and animals. Capable of combating the enemies invading the organism, without any distinction, in particular the bacterial pathogens, it has to be aided by the specific sensibilisatrice. This is secreted automatically by the organism when it is invaded by an alien cell or by an infectious agent.

The microbic invasion of an organism either experimentally or by disease provokes in the organism the elaboration of properties sometimes dissolving, sometimes agglutinating, sometimes both. Bacteriolysis is specific. The production of it can be determined experimentally by the inoculation of the animal with weak microbes.

We have seen that in these experiments Pfeiffer had determined the agglutination and the granular degeneracy of the cholera vibrios injected into the peritoneum of an immunized guinea pig. The same phenomenon was verified by other scholars for different microbes. Bordet has shown that these bacterial agglutinins resist heating at 56° C. The agglutinins are thus independent of alexin. It should be observed that the agglutinated microbes are not dead; sown on the culture media, they grow like normal microbes.

The organism can thus defend itself against the invading microbes by phagocytic action and by the elaboration of properties such as the sensibilisatrices, bacteriolysins, agglutinins, precipitins, etc. These substances may be united under the term antibodies. Other experiments have proved that only the substances which are of a protein nature, for example, those which are derived from animals or plants (cells, red blood corpuscles, milk, albumins, serums, microbes, etc.) provoke this elaboration of the antibodies. All the substances capable of inciting the formation of these antibodies are grouped under the term antigens.

BACTERIOPHAGE

There exists another principle of defense, mysterious because it remains sealed against our natural means of microscopic investigation and because agreement cannot be reached regarding its nature: It is bacteriophage.

The definition of it as given by Dr. D'Herelle, who discovered it, follows:

> The lytic principle, which I term *Bacteriophagum intestinale* or *Bacteriophage* is a particle that multiplies at the expense of the excretions of bacteria, capable in consequence of assimilation, which is indefinitely cultivable in series, in vitro, in its filterable form.

The bacteriophage is cultivable like the microbes but it only develops at the expense of living microbes. Sown in a culture of microbes, it provokes the clearing up of the cultures in liquid media and the formation of clear expanses in the cultures on solid media, phenomena that prove its power of bacterial destruction.

Its bactericidal action is manifested on a great number of microbes. For example, the Shiga dysentery bacillus, submitted at 37° during three-quarters of an hour to the action of the bacteriophage, shows a bad color; at the end of an hour of action, there may be found only granulations, residue of the microbian action. After 10 hours these granulations disappear and the bouillon becomes completely clear.

According to D'Herelle, the presence of the bacteriophage in the organism is manifested especially at the moment of convalescence. It resists heating at 75° and can be conserved in active culture for a long time. D'Herelle considers it an ultramicroscopic organism specifically pathogenic toward living microbes. In other words, the bacteriophage has the relation to the microbes that the microbes have to the animal organism.

Certain scholars share the views of D'Herelle; on the contrary, Bordet and others believe that the bacteriophage in reality is only a property acquired by the microbe itself; a nutritive vitiation which issues from the hereditary lytic principle. He has advanced weighty arguments in favor of this interpretation.

ANTITOXINS AND CRYPTOTOXINS

Roux and Yersin have been the first to discover that certain microbes are toxic to an organism because they elaborate poisons that are called toxins. These toxins, injected experimentally, are capable of provoking the same symptoms in the animals as does the illness of which the microbe is the agent; they can cause death. Injected in small doses, they stimulate the production by the organism of specific antibodies which are called antitoxins.

H. Vincent discovered that certain fatty acids in combination with alkalies have the remarkable property of neutralizing the most active microbic toxins, in almost infinitesimal doses. He has demonstrated that when some traces of these bodies are added to microbian toxins of diphtheria bacillus, *Clostridium tetani*, dysentery bacillus, colibacillus, *Clostridium oedematis maligni*, etc., they neutralize their pathogenic action after a contact of from some hours to 4 days, at a temperature of 38 to 39°, according to the nature of the substance and that of the toxin. The animals can support toxins thus treated up to doses of 500 to 1,000 times greater than one mortal dose not treated. At the same time, H. Vincent has shown that toxins influenced by this treatment are not entirely destroyed. They subsist in direct combination with the micella of the soaps adsorbed by them. If some acid is added to the tetanus toxin that has been treated and become inactive for the animal, and when this mixture is immediately injected, the animal has tetanus in a secondary weaker form. The toxin has thus been simply immobilized, disguised in the complex toxin soap. Professor Vincent has given to toxins in this state the name of cryptotoxins.

If, to the neutralized toxin, there is added, 4 or 5 days later, one-fourth or one-half cubic centimeter of fresh toxin, the mixture does not become toxic, which proves that the pure toxin has been neutralized biologically by an available surplus of the chemical antibodies. It is evident that this surplus is detached from the molecules of cryptotoxins to then fix itself on the micella of fresh toxin, because of the law of molecular attraction.

These researches have led this scholar, because of the similarity of mode of action of the antitoxins with that of the cryptotoxic agents, to formulate a theory of the general constitution of the antibodies founded on the laws of physical chemistry and of molecular attraction.

A diagram (fig. 4) synthesizes this theory of the constitution of the antibodies. *T* represents the toxin and *A* the antibody. The initial nucleus *TA*, neutral and irreducible from the antitoxic, becomes the center of attraction for the other free molecules of the toxin *T*. The whole $(TA) + A' + A'' + A''' \ldots$ thus constitutes an accumulation of antitoxic energy capable of neutralizing, thanks to the excess of A', A'', $A''' \ldots$ the new toxic micella T', T'', $T''' \ldots$ with which it comes in contact. It is to this supersaturation that the fact should be attributed that the serum of an immunized animal returns in antibodies to the hundredfold, that which this animal has received in antigens, that is to say in toxins (diphtheria, tetanus, etc.). This theory gives, according to Prof. H. Vincent, the interpretation of the therapeutic effects of the serums as well as the neutralizing action in vitro. It also explains, it goes without saying, the production of immunity in sick people.

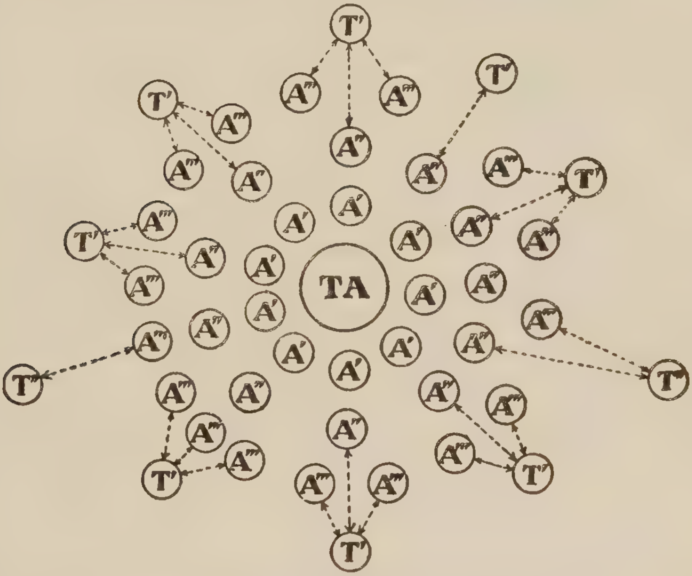


FIGURE 4.—Constitution of the antibodies, according to Prof. H. Vincent. *T*, toxin; *A*, antibodies.

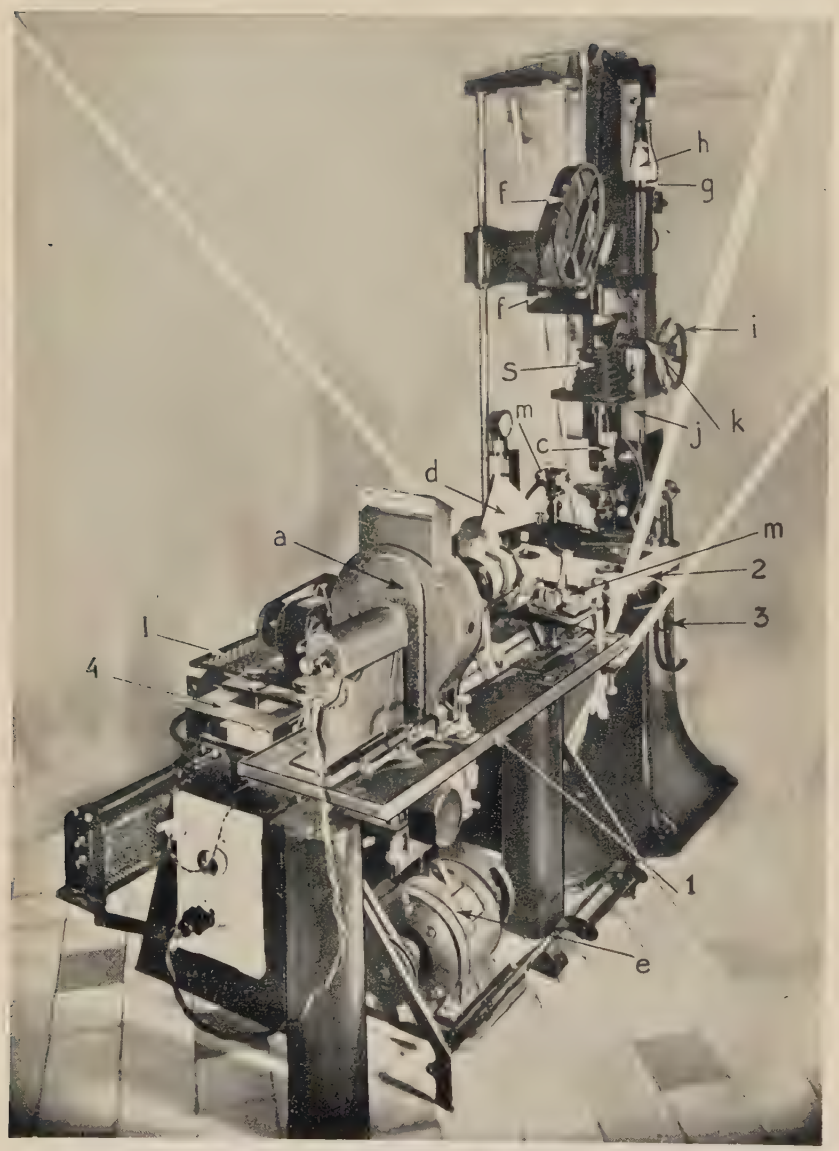
CONCLUSION

Just as there have been objections directed against phagocytosis being considered as the unique process for the defense of the organism, in the same manner, objections can be made to the theory of antibodies being considered as the explanation of all immunity. In effect, if the multiplication of the microbe is very rapid, if this microbe is too virulent, the organism does not have time to produce antibodies and it succumbs.

The existence of the sick person is the stake in the battle between the pathogenic microbe and the natural defensive elements (alexin) or the acquired defensive elements of the infected organism (phagocytes, bacterial antibodies, specific antitoxins, bacteriolysins, etc.). However, in a war, all the means of defense or attack should cooperate according to the plan of the whole. One can suppose that it is the same for the organism when the antibodies serve as auxiliary to the normal alexin to determine the destruction of the pathogenic microbes, while the antitoxins neutralize the microbian poisons. The role of the phagocytes is to bring about the definite disappearance (by engulfing and digesting) of the microbes thus attenuated or destroyed; but they can also destroy by themselves alone certain pathogenic microbes.

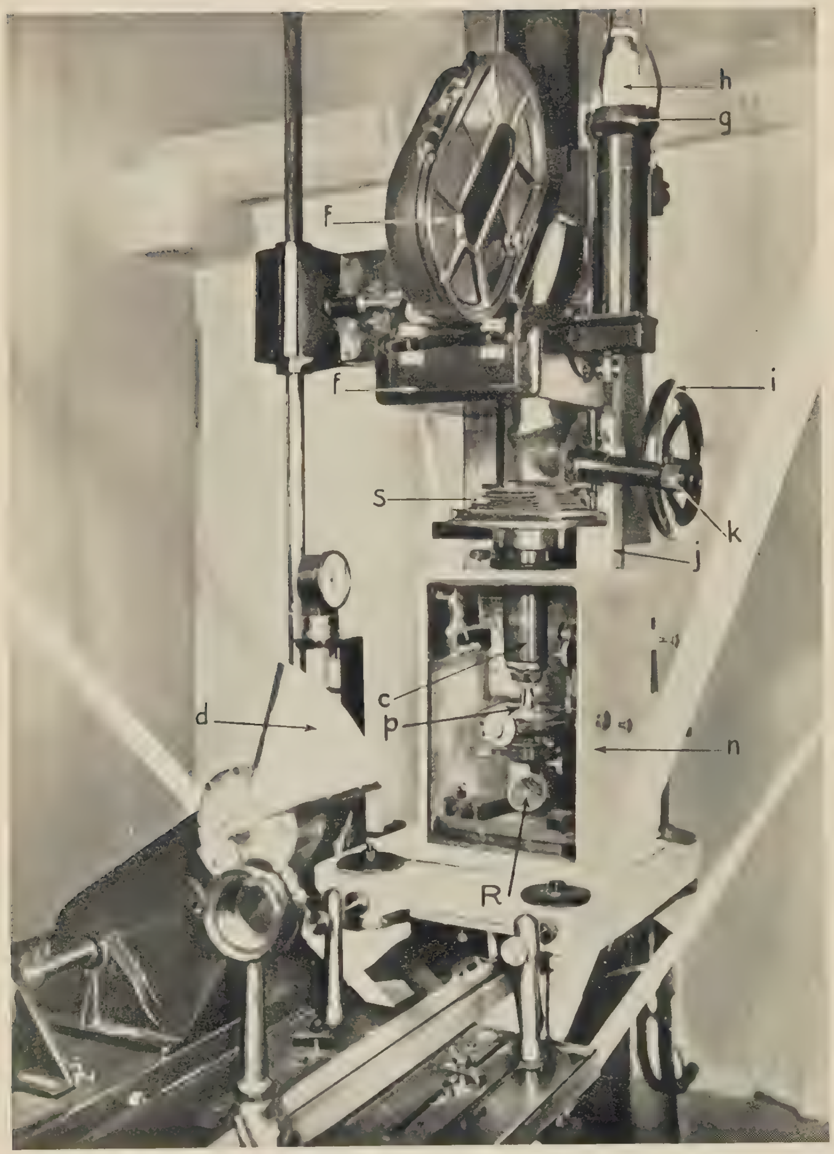
Good functioning of all of these elements of protection, either innate or acquired, is often determined by the general condition of the organism. Hygiene, healthy living, fresh air, physical exercise contribute to the strengthening of this state. On the contrary, lack of hygiene, alcoholism, excess, in a word, everything which causes the weakening of the organism, undermines the resistance and contributes to the victory of our enemies, the microbes.

Finally, in conclusion, let us recall that bacteriological science has discovered methods for reinforcing, by vaccination, by serotherapy, or by the introduction of various diverse chemical substances, the natural resistance against a certain number of pathogenic agents.



THE INSTALLATION OF DR. COMANDON'S MOVING PHOTOMICROGRAPHIC MACHINE.

1. Heavy table holding the light source *a* and the optical bench; 2, microscope platform *c*; 3, apparatus for taking the pictures; 4, steel table on which is the shutter *d*; *e*, electric motor; *m*, micromanipulator of de Fonbrune.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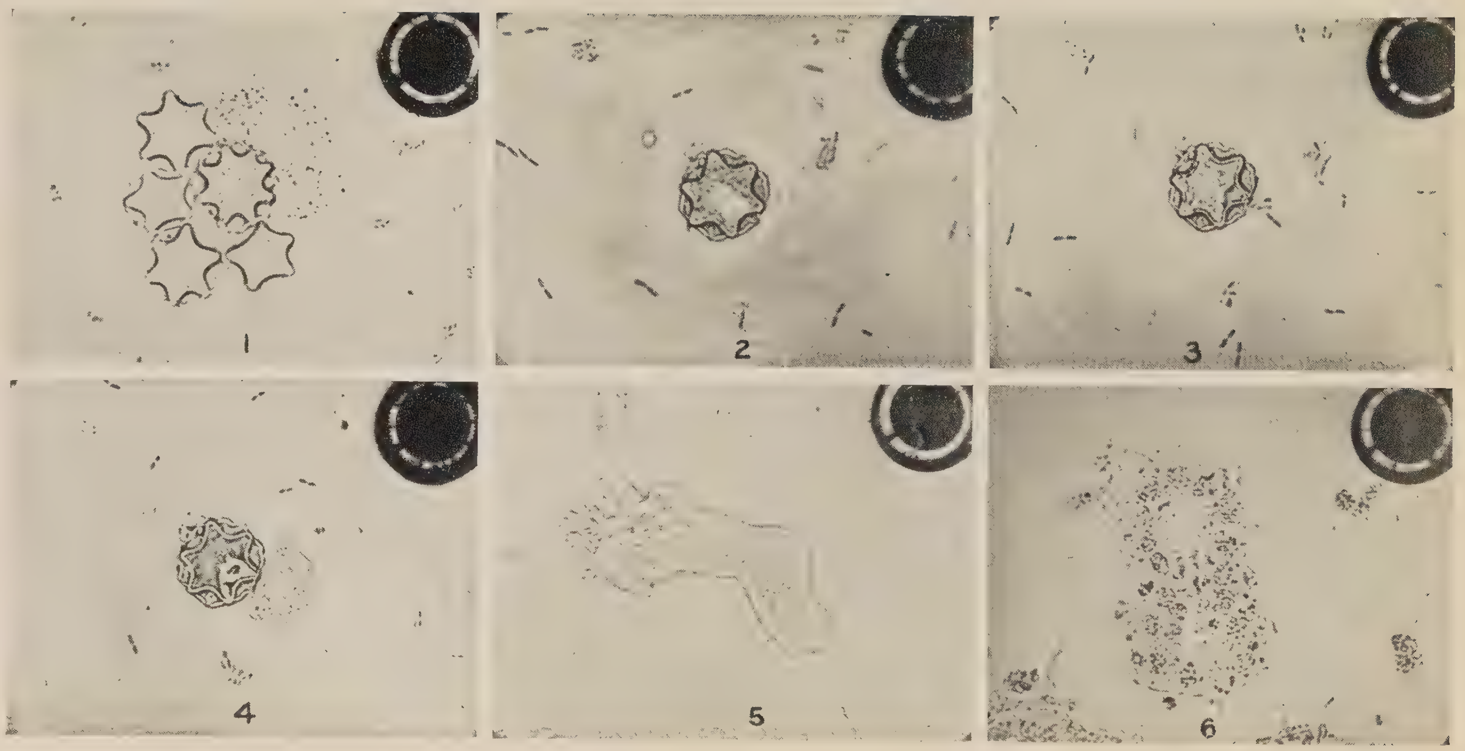
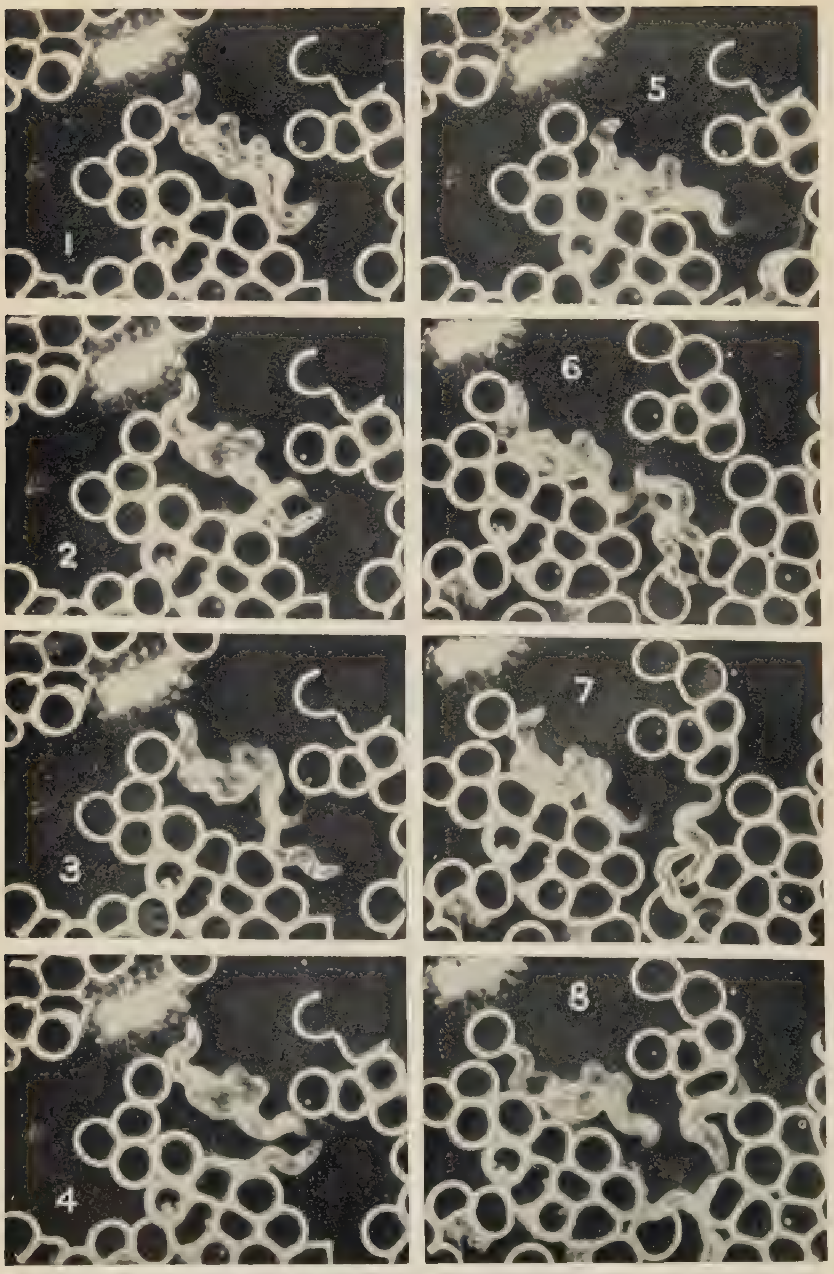
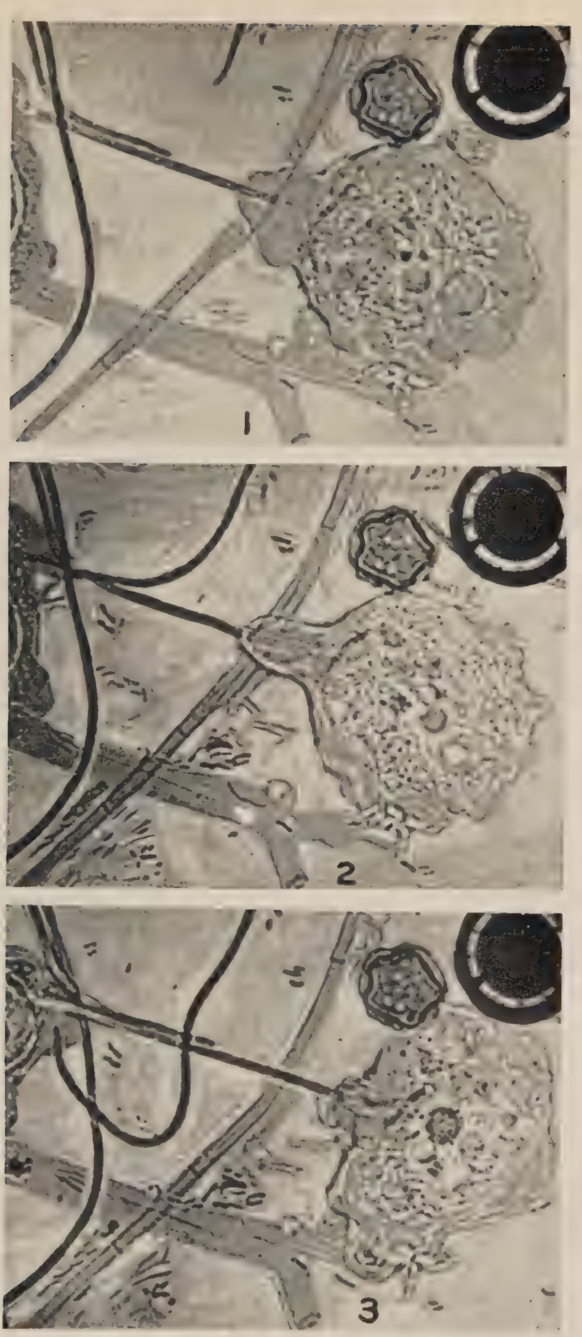
The microscope *c* placed in a controlled temperature chamber *n*.



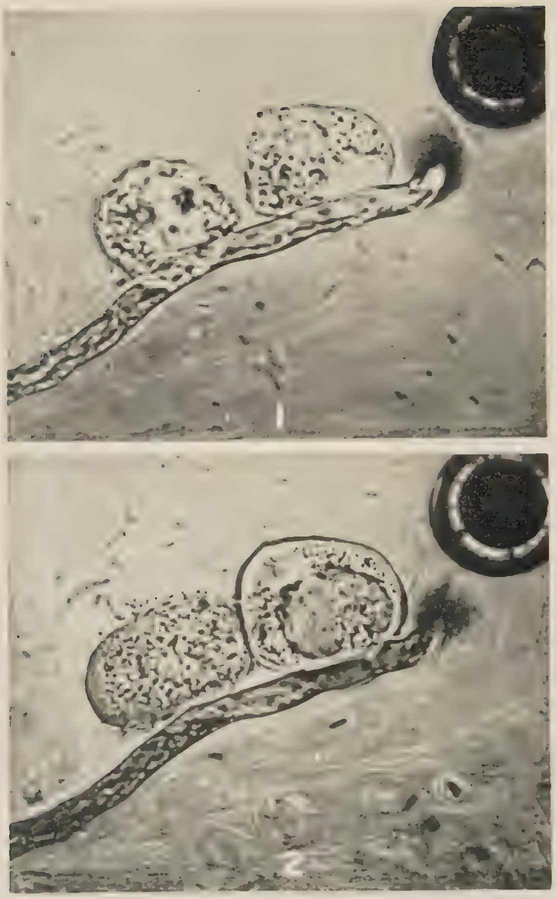
SUCCESSIVE PHASES IN THE OUTBURST OF AN AMOEBA FROM ITS CYST.



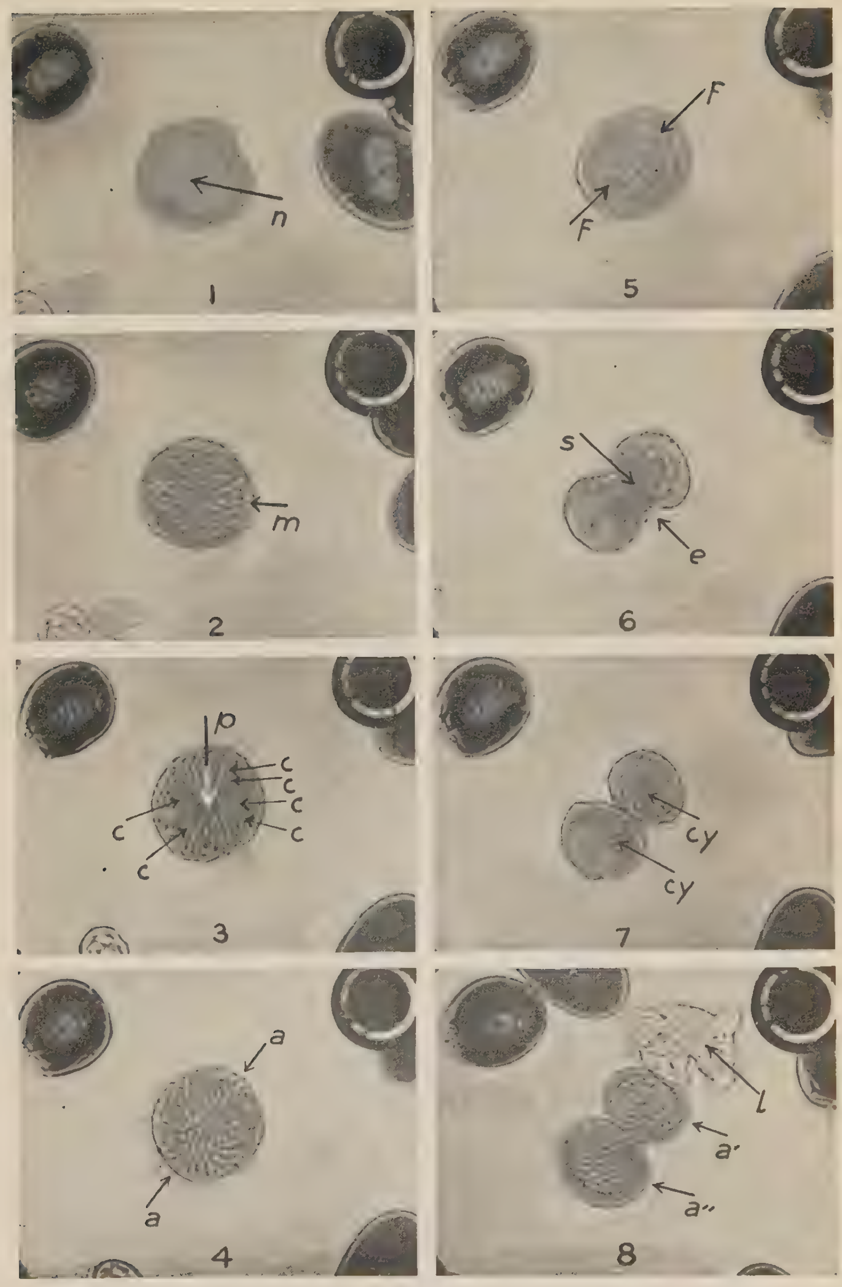
DIVISION OF A TRYPANOSOME IN THE MIDDLE OF RED BLOOD CORPUSCLES IN THE BLOOD



AN AMOEBA FEEDING ON AN ALGAL FILAMENT



Two Amoebae on a Mold Filament Which One of Them Perforates.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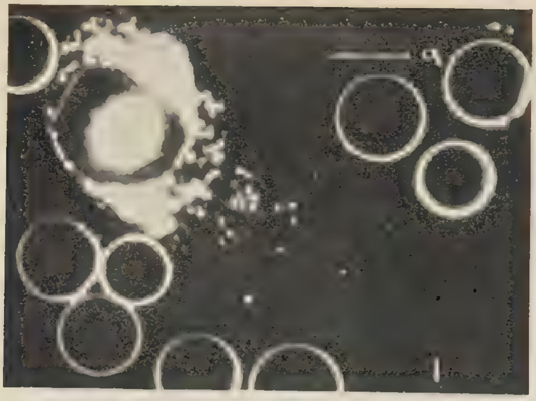
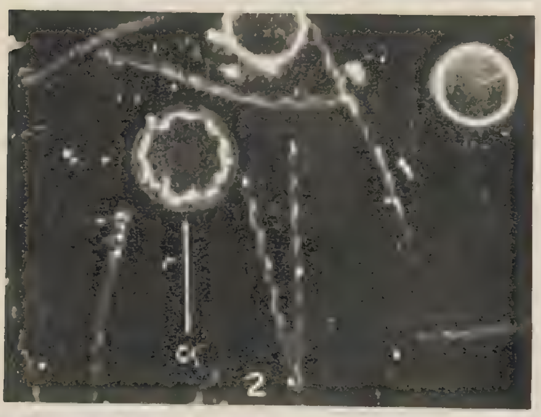
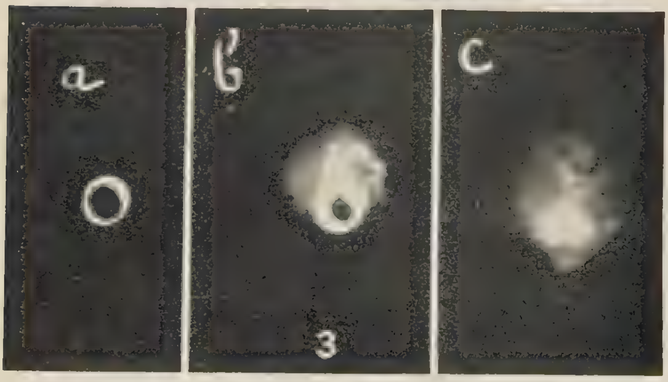
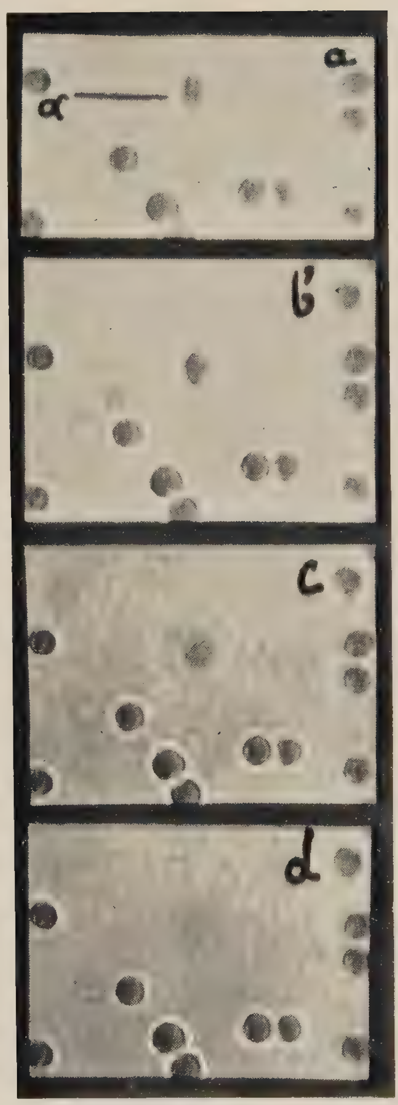
KARYOKINETIC DIVISION OF A RED BLOOD CORPUSCLE OF A TRITON.



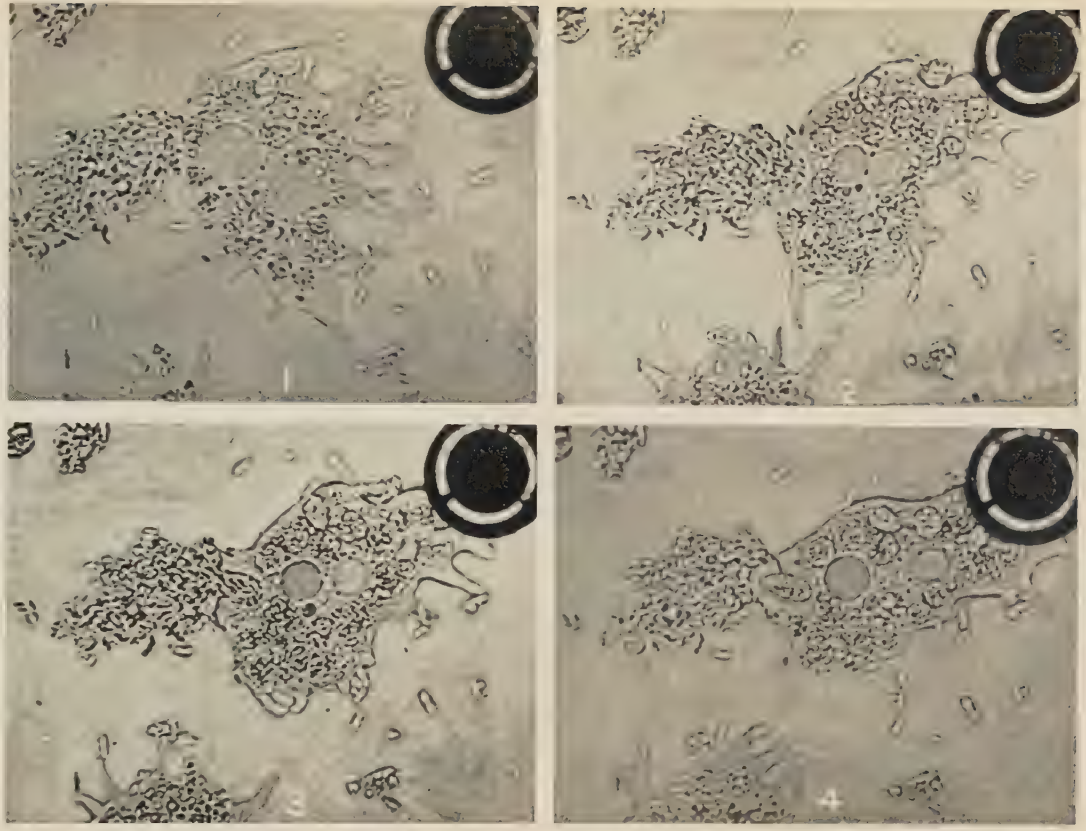




1. Haemolysis of the blood of a rat. In *a*, red blood corpuscle, scarcely visible. At left, a leucocyte that has burst.
2. Blood of a rat invaded by *Spirochaeta duttoni*. In *a*, spirochaete lodged in a globule.
3. Haemolysis of a human red blood corpuscle with 1/1000 N hydrochloric acid.



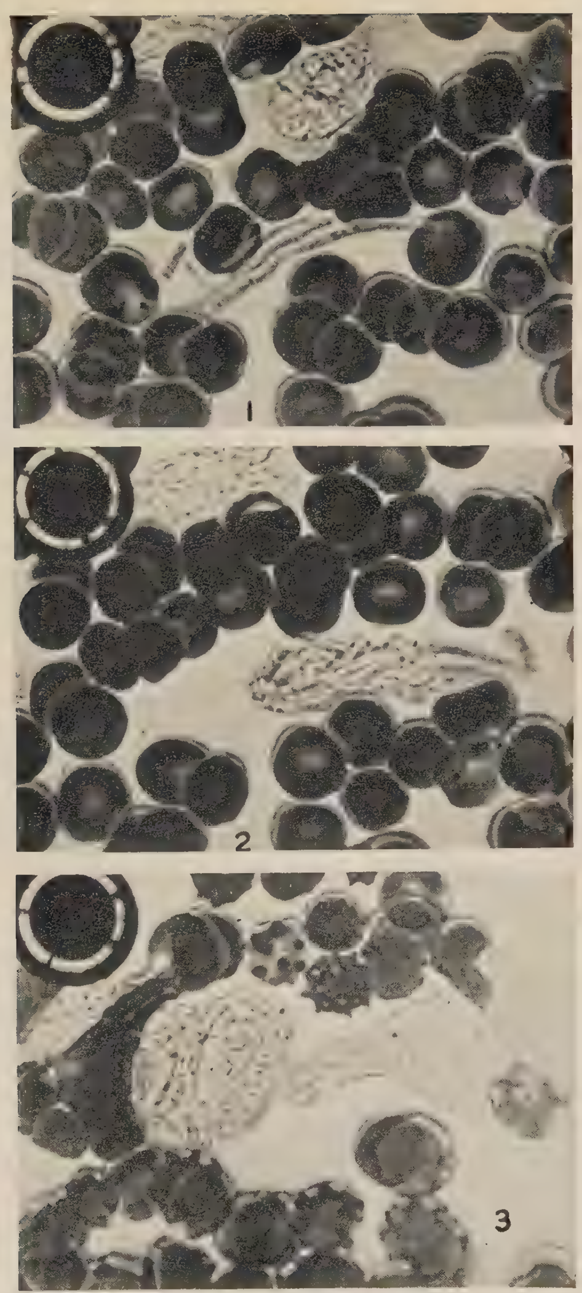
HAEMOLYSIS OF THE HUMAN BLOOD WITH BILE.
In *a*, globule rapidly disappearing.



Moving photomicrograph by Dr. Comandon and M. de Fonbrune

INGESTION OF MICROBES BY AN AMOEBA.

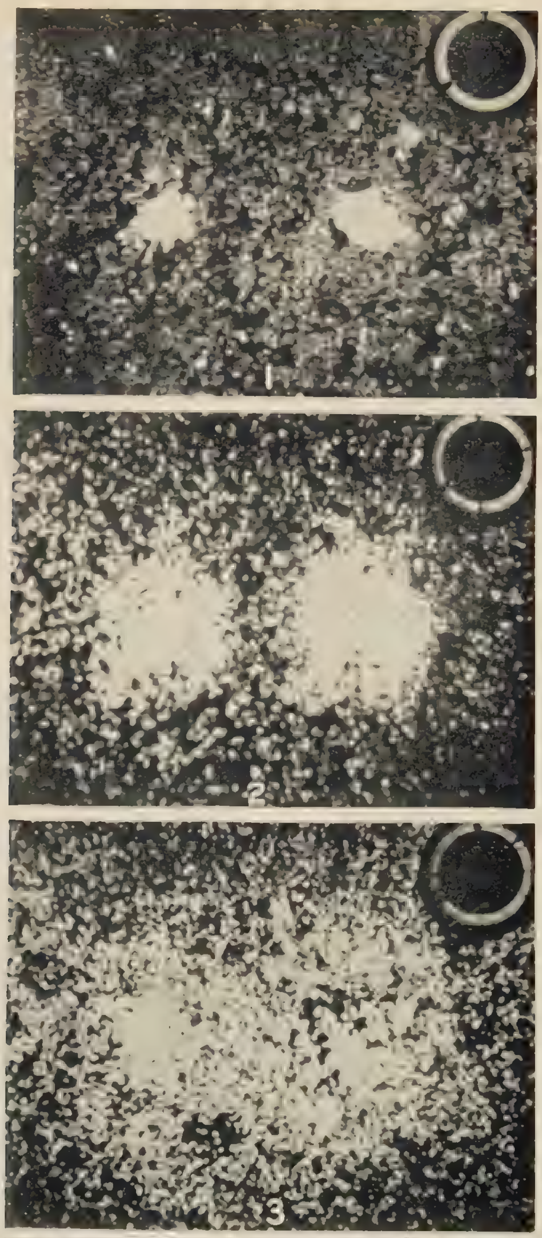
1. An amoeba becomes aware of a mass of microbes; 2, it commences to surround them with its pseudopodia; 3, a certain number of the microbes penetrate into the invagination; 4, they find themselves isolated in a digestive vacuole.



Moving photomicrograph by Dr. Comandon and M. de Fonbrune

INGESTION OF CARBON BACTERIA (B. ANTHRACIS) BY PHAGOCYTES OF THE BLOOD.

1. Some bacteria have been introduced into the blood (elongated rods in the center of the photograph); a leucocyte arrives (at the top) among the red globules (dark disks); 2, twenty-two minutes later, the leucocyte has ingested the bacteria; another appears at the top; 3, an hour later, other leucocytes are grouped about the first phagocyte.



Moving photomicrographs by Dr. Comandon and M. de Fonbrune

A MASS OF STREPTOCOCCI HAVE BEEN INTRODUCED INTO THE BLOOD (AT LEFT) AND A MASS OF DIPHTHERIA BACILLI (AT RIGHT).

1. The leucocytes (little white points) commence to arrive and surround the microbian mass; 2, six hours later, the masses are completely encircled and still other leucocytes continue to arrive; 3, six hours later, the diphtheria bacteria are destroyed, the streptococci still resist, the mass at the right is dislocated.

FRESH-WATER FISHES AND WEST INDIAN ZOOGEOGRAPHY

By George S. Myers
Stanford University

[With 3 plates]

INTRODUCTION

Since time immemorial man has enjoyed looking backward, but it is only within the last century that the researches of the geologist and paleontologist have allowed him to see the earth as it was before he himself existed. Nowadays the strange creatures that peopled the past even appear in the Sunday supplements and the cinema, and the fact that what is now dry land may have been under the sea is common knowledge. To the student of plant and animal distribution, or biogeography, the long-gone past is of particular interest. We know that many living things could not be found where they are if the land and sea had always been exactly as they exist today, and only a study of paleogeography, or the geography of ancient times, will enable us to understand how plants and animals moved about over the face of the earth and reached the places where we now find their living descendants.

Students of both phytogeography, or plant distribution, and zoogeography, or animal distribution, must depend largely on the geologist to tell them how the land and sea were bounded in the past, but often they can help the geologist in this very matter. Studies of the relationships of living things, both recent and fossil, frequently point out that two islands or continents must have been connected by dry land at a certain geological time, for example the connection of Alaska with Siberia across Bering Strait. In the same way the close relationship or identity of various species of fishes and other marine animals on the Pacific and Atlantic coasts of Panama show that the two oceans were once connected over what is now the isthmus, and at no very distant period, geologically speaking. In fact, the geologist often depends to a considerable extent on the fossil remains of once-living creatures for information about his rock formations, their age and the climatic and other conditions under which they were deposited, as well as for hints as to probable land and sea connections in the past. Biogeographical studies, then, interlocked as they are with geology and paleontology, contribute to two different fields, primarily to a knowledge of how living things evolved and migrated and secondarily to a better understanding of the changes of land and sea areas and of climate during geological time.

For many reasons, biogeographical problems are often difficult to solve, although some workers have been slow to realize this difficulty. The classical distributional researches of Darwin, Wallace, and their contemporaries threw a bright light on subjects that had been little thought about, and many of their followers lost sight of the fact that the most brilliant of the first results were drawn from those instances in which plain evidence was lying fallow to produce richly for those first in the field. Year by year the literature of biogeography grows, and as vast new stores of precise facts pile up, problems that formerly seemed simple become increasingly difficult to solve. Indeed, it is apparent that the data of the science are already too vast for any single person to digest, even in relatively circumscribed problems. Most biogeographers of today are of necessity narrower specialists than their predecessors; each has a large and growing body of fact in his own specialty to master and less time to acquire the geological background and knowledge of the literature of other fields that would enable him to see distributional problems in true perspective. It would seem that general biogeographical results of lasting value can be reached nowadays only through the cooperation of a group of competent specialists who can weigh apparently contradictory evidence and reach conclusions in accord with the soundest bodies of biological, ecological, paleontological, and geological fact.

ZOOGEOGRAPHICAL PROBLEMS OF THE AMERICAS

Biogeographical problems are legion, ranging from questions of continental and oceanic relationships to minute details of the distribution of single species, but at this time I wish to speak only of a very few of the broader problems of the animal geography of North and South America.

Generally speaking, zoogeographers, like Gaul, are divided into three parts—those who build bridges, those who do not, and the proponents of continental drift. To begin with the last first, it may be explained that Wegener and his followers believe that all the continents once formed a more or less compact land mass floating upon the deeper, heavier rocks of the earth's crust, and that sundry pieces of this land mass broke off from time to time and drifted away to form what we now call Australia, the Americas, and Africa. Despite the fulminations of those opposed to this theory, there is a considerable body of weighty evidence in favor of it, and I for one, should not be surprised to see it finally prevail. However, there is just as weighty authority against it, and since the fishes might be construed as favoring either side of the argument, I shall not now consider it further.

The bridge builders are those zoogeographers who are prone to postulate vast continental connections, which they believe existed in what is now the deep sea, in order to provide bridges over which the land faunas could march to destinations to which they obviously got somehow. The more radical of this school frequently sink (in theory) whole halves or quarters of continents to the deep sea and raise vast areas of ocean bottom into new continents to explain their ideas of how living things evolved and migrated. Unfortunately, there is little geological evidence for the more bewitching of these schemes, and zoogeographers are coming to depend on them less and less. To my mind, the most sensible of these "bridges" are the narrow and not at all startling "isthmian links" of Willis (1932) and Schuchert (1932); they have the unique backing of what appears to be sound geological and bathymetric support, and in addition, some of them are still in existence either as true continental connections (Panama) or chains of islands (West Indies).

Those who do not build bridges are the zoogeographers who, since the time of Wallace, have held sternly and perhaps a little too tenaciously to the theory of the "permanence of the ocean basins." They do build bridges, but very modest ones. They hold that, by and large, the only areas that have ever been dry land are those either now dry or a part of the continental shelves, that parts of continents have been flooded but never deeply, that no major portion of the really deep-sea bottom has ever been upraised into dry land, and that the small land bridges they postulate can account for all the migrations of land animals that have occurred. It must be admitted that this school has been the most cautious in examining the available evidence and the most erudite in its researches; of late years it has also been the most stiff-necked in considering contrary opinion. Its foremost recent exponent has been the late W. D. Matthew, whose Climate and Evolution (1915) has had a profound and overwhelming effect on nearly all recent American vertebrate zoogeographers, and but little on anybody else. There is no doubt, however, that Matthew's views deserve the most careful consideration, and it is unfortunate that he did not live to write the proposed enlarged and revised edition of his work.[1]

Matthew's thesis was, briefly, that "secular climatic change has been an important factor in the evolution of land vertebrates and the principal known cause of their present distribution" and that, in later geological epochs, most continental groups of animals have originated in the great northern land mass of Eurasia and North America

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[1] For which I had gathered the ichthyological information.

(the Holarctic region) and migrated outward, radially, into South America, Africa, and the Indo-Australian region. On a globe, or a north-polar projection of the world, such evolution and migration is easy to visualize; Eurasia and North America, which have frequently been connected, form a preponderating land unit, from which the other continents radiate. I think no serious zoogeographer can disagree radically with Matthew's view that secular climatic change has had an enormous effect on animal distribution, but it is questionable that climate has directly influenced evolution itself.[2] In regard to his postulation of a northern origin of the faunas of South America and other southern continents, however, it should be observed that von Ihering (1907), Eigenmann (1909), and other eminent men have come to a directly opposed conclusion, which emphasizes the relationships of certain African and South American animals that they believe did not originate in the north, and which, therefore, would demand some sort of South Atlantic land bridge to account for their evident community of origin. The necessity for a South Atlantic bridge has also been strongly advocated by so eminent an authority as Regan (1922), whose thoroughly sound data on the ostariophysan fishes are of the greatest importance.

In reviewing the distribution of American continental faunas in connection with some recent studies of West Indian fresh-water fishes, I have been struck with the amount of misinformation that passes as sound ichthyological evidence among zoogeographers. Part of this is the fault of the ichthyologists themselves. Papers on fish distribution written by competent ichthyologists and based on modern paleontological and ichthyological data are scarce, and the distributional information in two recent general textbooks on fishes (Kyle, MacFarlane) is scarcely to be relied on. On the other hand, the recent dependable papers that do exist have been neglected by most students of zoogeography. I have come across no modern paper that summarizes the broader geographical aspects of the fresh-water fishes of North and South America, and, in the belief that such may be of some general interest, I shall attempt to supply this want in very brief form. At the same time I shall speak about some of the implications of fresh-water fish distribution in the controversial question of West Indian paleogeography, but, in compliance with my thesis that biogeographical problems cannot be solved on the evidence of one group, I shall not pontify on matters I know I am not competent to settle.

WHAT ARE FRESH-WATER FISHES?

The importance of fresh-water fishes to students of geographical distribution depends primarily on two facts. Firstly, certain families of fishes possess an ancient physiological inability to survive in salt sea water, which binds them to the land as securely as any known animals Secondly, on the land, they are inescapably confined to their own particular drainage systems and can migrate from one isolated stream basin to the next only through the slow physiographical change of the land itself (stream capture, etc.). Throughout the world the migrations of fresh-water fishes over extensive continental areas have generally been excessively slower than those of almost any creature that can creep, crawl, walk, or fly, however closely that creature may have been bound by its ecological tolerances. This is exceptionally well illustrated by Central America, where the interpenetration of North and South American faunas has proceeded in many groups practically to the limit of climatic tolerance, but where no truly Neotropical (South American) fresh-water fish has gotten farther north than Texas or New Mexico, and none truly Nearctic (North American) farther south than Nicaragua.

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[2] Except as one of the factors of natural selection.

There are, of course, exceptional methods by which fishes may be transported. "Rains of fishes" are sufficiently well known and authenticated to make it certain that cyclonic winds, in passing over bodies of water, sometimes pick up small fishes and deposit them at a distance, still alive. It is possible, too, that a fish eagle or gull might drop or disgorge alive a newly caught fish after having carried it over a divide between two distinct river systems. But the frequently made statement that the eggs of fishes are dispersed by adhering to the feet of wading birds in flight should cease to trouble zoogeographers; such a method of transportation is possible, but almost no fish eggs are sufficiently resistant to survive drying in the air more than a very few minutes. The main fact to keep in mind is that fish distribution is much more regular and understandable than it would be if these unusual methods of transportation were of much importance.

One fact that some zoogeographers who have dealt with fishes have neglected is that the fishes to which the adjective "fresh-water" is applied differ widely in the extent of their tolerance of salt water. There are fresh-water fishes which never swim into salt water, some which occasionally do but can survive it only for a short period, some which habitually frequent estuaries and other brackish waters and frequently enter the sea, and some which migrate back and forth between river and sea either continually or periodically. It is plainly evident that a fish which can swim through sea water from one river mouth to another is not of much use in studies of terrestrial zoogeography.

The only fresh-water fishes that need especially concern us at present are those of the first two of the categories I have just mentioned. These two categories I shall distinguish as a *primary division* whose members are very strictly confined to fresh water, and a *secondary division* whose members are generally restricted to fresh water but occasionally enter the sea voluntarily for short periods. The other groups not specifically placed in divisions grade off into wholly marine forms. Finally, there are a number of species and genera of salt-water families that have taken up more or less permanent residence in fresh water. Most of them return to the sea to spawn.

THE GROUPS OF FRESH-WATER FISHES

The fresh-water fishes of the primary and secondary divisions tend to group themselves on natural family lines. In other words, all or nearly all species of one family usually show a similar tolerance to salt water. This, together with the fossil evidence available, leads us to believe that most of the families of the primary division have carried down their physiological inability to survive in the sea, as family characters, from early times and probably since the origin of the groups concerned.

The *fresh-water fishes of the primary division* are of diverse relationships among fishes generally. A few of them are small, relict groups of primitive organization, such as the two living families of lung fishes (Ceratodontidae, with one surviving species in Australia, and Lepidosirenidae, with three surviving species of the genus *Protopterus* in Africa and one of the genus *Lepidosiren* in South America). Of similar relict distribution are the two living genera of the primitive paddle-fishes, *Psephurus* in the Yangtse River in China and *Polyodon* in the Mississippi. Higher on the scale of fish evolution are the paleoniscidlike bichirs of Africa and the family of bowfins, with one living North American species. Somewhat similar to these last are the "ganoid" garpikes of North America, a family which I place, somewhat hesitantly, in the secondary division of fresh-water fishes.

The bulk of living sea fishes are of more specialized organization than these primitive families, and belong to the great subclass of bony fishes, or Teleostei, and this is true of the fresh-water families as well. The lowest order of teleosts is that of the herringlike fishes (Isospondyli) and to it belong several families of my primary fresh-water division; among them the hiodonts or mooneyes of the Mississippi; the strange phractolaemids, pantodonts, kneriids,[3] and mormyrids of Africa; and the ancient osteoglossids, which were probably well-nigh cosmopolitan in Eocene fresh waters.

More than half of the true fresh-water fishes of the world belong to a single order, the Ostariophysi,[4] distinguished from the herrings by the peculiar chain of Weberian ossicles connecting the air-bladder with the auditory apparatus. The ostariophysans are primarily a fresh-water order and must have been since their pre-Eocene origin; out of nearly 30 families and 4,500 or more species of them only 2 specialized families (the ariid and plotosid catfishes), comprising not over 150 species, are marine, and these beyond reasonable doubt are descended from ancient fresh-water ancestors. To the Ostariophysi belong the hordes of carps or minnows, suckers, loaches, characins, gymnotid eels, and bewhiskered catfishes that swarm throughout the rivers and lakes of all the continents except Australia. The only fresh-water Ostariophysi of Australia and Madagascar are ariid and plotosid catfishes that have reinvaded the rivers from the sea.[5]

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[3] The Nilotic Cromeriidae seem to be larval Kneriidae.

[4] See Regan (1922). A few characins, carps, and fresh-water catfishes enter brackish water in estuaries, but none is known to be able to survive in the sea for more than a few hours; none could breed there. The only exception of which I know is the carp *Acahara hakonensis*, which Prof. J. O. Snyder tells me is occasionally taken in the open sea off southern Japan.

The remaining fresh-water groups of the primary division are quickly enumerated. The rather herringlike order Haplomi contains the pikes or pickerels, the small mud minnows, and the Alaskan and Siberian blackfish. To some extent transitional from the foregoing, more primitive, bony fishes to the more highly developed, spiny-rayed types, are the strange percopsids and pirate perches of North America. Of the cyprinodonts I consider that only one family, the North American cave fishes, belongs to the primary division. Of the fully developed, perchlike groups we have the North American sunfishes or basses, the true perches of North America and Eurasia, and the tropical nandids. Ending the series are the Old World tropical labyrinth fishes and the isolated spiny-eels.

The *secondary division of fresh-water fishes* is composed of families which, in general, behave like true fresh-water fishes, but whose members show a less sharp restriction to fresh water. Among the more important of them are the North American garpikes, the synbranchid eels, the cichlids, and the various families of topminnows or cyprinodonts. Garpikes are known to enter the sea along the Gulf of Mexico coast. Most cichlids can survive several hours or days in the sea, and one species of *Tilapia*, collected in brackish water in Mozambique, has been kept for months in sea water at the New York Aquarium. Many cyprinodonts do not seem to be inconvenienced greatly by salt water. *Mollienisia latipinna* enters the sea freely and multiplies in brine ponds about Manila Bay, where it was accidentally introduced. Metzelaar reported *Rivulus* from tide pools on Curaçao, and certain species of *Fundulus* and *Cyprinodon* live permanently on the seacoast beyond reach of estuaries. The *Challenger* even caught a *Fundulus* in a mid-Atlantic pelagic haul! It is evident that many species of this secondary group might easily survive a short sea journey. This is borne out by distributional fact. It is only members of the secondary group that have succeeded in crossing to the east of Wallace's Line [6] in the East Indies, and in reaching Madagascar.[7]

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[5] It seems probable that the supposed Bourbon catfish *Laimumena*, close to certain South American trachycorystids, is based on mislabeled type specimens.

After this second group comes a succession of families of catadromous or anadromous fishes such as the fresh-water eels, the salmon and trout, the sturgeons, the galaxiids and the aplochitonids, and others which, for one reason or another, enter the sea freely and are in most cases not of use in studies of the distribution of fresh-water fishes. Lastly we find primarily marine families such as the sharks, herrings, gray mullets, sea basses, and gobies, a few of whose members have invaded the rivers and sometimes developed into purely fresh-water species.

THE FRESH-WATER FISH FAUNAS OF THE AMERICAS

1. LIMITATION TO TERTIARY

In the mammals, the history of many of the modern orders has been traced back to their very different Eocene ancestors and considerable has been done in connecting these up with Mesozoic forms. The story of the continental fishes is very different. The Ostariophysi, as well as nearly all other groups of fresh-water bony fishes, are known only as far back as the early Tertiary, and the few known Eocene fossils usually turn out to belong to still living genera or their very close relatives. It would seem that the evolution, from very primitive types into practically modern forms, of a whole series of the major groups of fresh-water (and marine) bony fishes occurred between the end of the Cretaceous and the earlier Eocene. What little we know of Paleocene fishes is mostly from marine deposits, and the derivation and evolutionary lines of the Ostariophysi and most other fresh-water groups remains a closed book. The locating of early Eocene and Paleocene fresh-water beds and the working out of the history of the fishes remains one of the greatest untouched problems in vertebrate paleontology, and one in which American paleontologists, at least, have taken strangely small interest. It is evident that we can draw no definite conclusions regarding pre-Tertiary geography from the fresh-water bony fishes, and but little about post-Mesozoic from such primitive relicts as the lungfishes and bichirs.

2. NORTH AMERICA

The greater part of the Tertiary and recent fresh-water fish fauna of North America is divisible into two sections. The first forms the old, endemic fauna composed of paddlefishes, garpikes, bowfins, osteoglossids, suckers, ameiurid catfishes, primitive cyprinodonts, and pirate-perches. All of them are known to have been present in the Nearctic Eocene and all survive in North America today save the osteoglossids and primitive cyprinodonts; the last are probably represented by the existing cave fishes. The paddlefishes are recorded from the English Chalk and now exist in China; the bowfins are as old as the Jurassic and are found in the Mesozoic rocks of Europe, Brazil, and North America; and the garpikes occur in the Cretaceous of Europe and the Lameta beds of India. All three groups are too old to enter decisively into our discussion of the Tertiary fishes. The suckers are found in the Eocene of Wyoming, and Hussakof (1932) has reported isolated gill covers from the Eocene of Mongolia; there is one specialized genus now living in China and one North American species has invaded Siberia, probably recently. The ameiurid catfishes are represented in the Green River Eocene by *Rhineastes* and appear to be a purely North American group related to the Old World bagrids.[8] A supposed living Asiatic species based on a Chinese painting is almost certainly mythical. To the old section probably belong the North American sunfishes or basses,[9] and the peculiar percopsids, the geological history of which is nearly or quite unknown. The bulk of the North American fresh-water fish fauna of today is made up of the members of the carp or minnow family. Fossil carps are unknown in North America until the Miocene, at which time the family evidently arrived from Eurasia to form the second or younger section of the fauna. This invasion was made up entirely of the second most primitive (Leuciscinae) of the three great subfamilies of Cyprinidae (Regan, 1922). Lack of clear paleontological evidence does not allow us to say whether or not the Eurasian-American true perches are autochthonous North Americans. Genera supposed to be perches are recorded from both the American and European Eocene. If Voigt (1934) and Berg (1936) are correct in associating the short-jawed middle Eocene *Palaeoesox* with the pikes and mud minnows, the order Haplomi probably originated in Asia and may have invaded America with the carps. The mud minnows,[10] unknown as fossils, have two genera and three American species. The pikes have several North American species [11] and have existed in Eurasia at least from the Oligocene to the present.

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[6] It seems probable that the presence of the air-breathing climbing perch (*Anabas*) east of Wallace's Line is due to human introduction. *Anabas* is much carried about as a food fish. As to the osteoglossids, see further on.

[7] *Etroplus*, the only Indian cichlid, is confined to the southern Indian Peninsula and is closely related only to certain Madagascan species; it perhaps arrived in India by sea via the Seychelles-Chagos-Maldive chain.

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[8] Regan (1922). Hussakof (1932) records fin spines of *Rhineastes* from the Pliocene of Mongolia. If these are really generically identical with the skulls from the Bridger and Green River, they indicate that the ameiurids were a Holarctic group.

[9] Since this paper was written, Schlaikjer (1937) has described a sunfish from an unplaced Tertiary formation in Alaska. His attempt to see similarities to the sunfishes in certain Asiatic fresh-water serranids is scarcely convincing, and his supposed fossil sucker, of which practically no description is given, is probably a carp. If Regan (1916) is correct in referring *Priscacara* to the sunfishes, the family has existed in North America since the Eocene.

[10] For the present purpose I include in the Umbridae the peculiar relict *Novumbra*, recently discovered by Schultz in western Washington. The Alaskan and Siberian blackfish is of little importance to our discussion.

[11] I have examined a large jaw of *Esox lucius* or *E. masquinongy* from the Pleistocene of Florida (specimen in U. S. National Museum).

3. SOUTH AMERICA (AND AFRICA)

In South America we have a very different picture.[12] The known fossil record is so fragmentary as to be of no particular importance, but the living fishes are exceedingly instructive. Of the living true fresh-water fishes of South America, not a single species, genus, or family is identical with truly North American groups. In fact the South American fishes show greater dissimilarity to those of North America than they do to those of any continent except Australia, which has no fresh-water fishes at all of my primary division save for one lungfish and one osteoglossid.

Certain apparent similarities are at once disposed of. The primitive bony fishes of the family Osteoglossidae, which appear to have become extinct in North America in the Eocene, exist today in South America. But they also exist in Africa, the Malay Archipelago, and Australia, and, as I shall show a little later, I believe that their mere presence loses any great significance in Tertiary zoogeography. Single species of the South American characins and cichlids have reached Texas, but in each case the migrant is a generalized, aggressive fish, the recent migration path of which is clearly evident. The cyprinodonts form a different type. The viviparous cyprinodonts of the family Poeciliidae are common from Delaware, Illinois, and Arizona to western Ecuador and northern Argentina. Unknown as fossils, they may have developed in Central America, possibly from ancestors similar to the goodeids, which are autochthonous in the Mexican plateau. The oviparous cyprinodonts of the family Cyprinodontidae likewise occur from central North America to Argentina, but it has recently been shown (Myers, 1931) that the dominant South American genera are closely related to African rather than to North American forms.[13] At any rate, all the cyprinodonts except the North American cave fishes belong to the secondary class of fresh-water fishes.

South America is the richest of all the continents in fresh-water fishes. The largest section of the fauna is formed by Ostariophysi. Five families of characins are found of which only one, the most generalized, is shared with any other continent (Africa). There are 11 families of catfishes, as well as the gymnotid eels, none of which are found anywhere else save for a few aggressive migrants which have pushed up into Central America. The only other South American fresh-water fishes of the primary class are the lungfishes (one species)[14] and the nandids (two genera and two species).[15]

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[12] The peculiar, depauperate, Patagonian fauna is not here considered. Its only close relationship, as shown by the lampreys, galaxiids, and aplochitonids, is with New Zealand and South Australia, and this points to either an Antarctic connection or sea migration, which I do not think impossible for any of the three groups.

[13] Except for the semimarine subfamily Cyprinodontinae of southern North America and the Caribbean, of which *Carrionellus* is known from the Tertiary of Ecuador. The exact relationship of the autochthonous Orestiatinae of Lake Titicaca is unknown.

Of the secondary class of fresh-water fishes, the most numerous in South America are the cichlids; the genera seem to be more diverse than the African ones, though the number of species is smaller. The cyprinodonts have already been mentioned.

In order that the reader may appreciate the evident relationship with Africa displayed by many South American fishes, it is necessary to add a few words on the Ethiopian fish fauna. This is definitely composed of two main elements, one a group of primitive and undoubtedly ancient fish families that are unknown outside Africa either fossil or recent and that in all likelihood evolved there, and a preponderating fauna of migrants which reached and flooded the continent in later times. To the old group belong the bichirs, pantodonts, phractolaemids, kneriids,[16] and mormyrids. Undoubtedly existing there with them were the old ubiquitous osteoglossids, which may have given rise to the pantodonts and of which a single species still persists today. To the later invaders belong the teeming present-day African characins (of two families, one held in common with South America), cichlids, labyrinth fishes, carps, and certain catfishes. The carps undoubtedly arrived only in the middle or late Tertiary from southern Asia; their many species have mostly not yet become generically distinct from their Asiatic relatives. The characins and most of the catfishes were undoubtedly present in Africa before the arrival of the carps. Some of the families of catfishes (electric catfishes, mochokids, and amphiliids) and one of characins (citharinids) probably evolved there, the latter certainly out of the Characidae. The Characidae, cichlids, nandids, rivuline cyprinodonts, lungfishes, and osteoglossids are held in common with South America, but it has already been noted that the last-mentioned family is probably of no great importance in this connection, and the same is possibly true of the lungfishes. It is of especial importance to note that not one of five primitive, autochthonous, African families, that were in all probability in Africa before the characins, cichlids, and carps, are held in common with South America.

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[14] *Lepidosiren.* The only other living species of Lepidosirenidae are the three *Protopterus* of Africa. The Australian *Neoceratodus* is very different.

[15] *Polycentrus* and *Monocirrhus* are closely related to the Nigerian *Polycentropsis* and the Indian *Nandus.* The Indian *Badis* is very distinctive and probably should form a separate family. It is close to neither *Nandus* nor *Pristolepis.*

[16] Following up Pellegrin's recent comparison of the peculiar Nilotic cromeriids with larval albulids, and his hesitant suggestion of kneriid relationship, I shall be greatly surprised if *Cromeria* is found to be anything but a larval *Kneria.*

4. CENTRAL AMERICA

The Central American fish fauna is a strange mixture of North and South American types.[17] Of the purely North American fishes, the garpikes have gone farthest south, having reached Lake Nicaragua, and their invasion was likely a fairly old one. The ameiurid catfishes and the suckers have gotten as far as Guatemala, the carps to central Mexico, and the perches and sunfishes only to northern Mexico. Of the South American families, the loricariid, astroblepid, callichthyid, and pygidiid catfishes, and four of the five families of Neotropical characins have gotten only a slight hold in Panama and Costa Rica. The gymnotid eels range north to Guatemala, the pimelodid catfishes to southern Mexico and Yucatan, the cichlids to Texas and the fifth family of characins to New Mexico. None of these northern or southern invaders save the cichlids has produced many startling endemic forms in Central America. The genera are few in number, almost all identical with those in North or South America, and represent merely a few of the most aggressive frontiersmen of dominant families.

In the cichlids, however, there has been an extremely rich flowering of species of the South American genus *Cichlasoma*, some of them distinct enough to be placed in different genera. But the cichlids are probably among the youngest of the coterie of fresh-water fish families, and their active recent evolution in the African lakes makes it seem probable that their numerous, closely related, Central American representatives are rather young. Certain it is that the South American *Cichlasomas* are less specialized than the Central American.

It is among the top-minnows or cyprinodonts that we find the most distinctive Central American fresh-water fishes. The most primitive living genus of the oviparous family Cyprinodontidae (*Profundulus*) is confined to southern Mexico and Guatemala, and from ancestors not very different from it probably arose the peculiar viviparous family Goodeidae, which is practically confined to the Rio Lerma Basin in Mexico. Returning momentarily to the Cyprinodontidae, a peculiar genus (*Garmanella*) related closely only to a Florida form (*Jordanella*) occurs in Yucatan, and the remarkable *Oxyzygonectes* is found only in Pacific Costa Rica; both are related to northern types, as is *Profundulus*. Of the southern rivuline group, *Rivulus* alone is found, as far north as Yucatan. Of the more advanced viviparous cyprinodonts (Poeciliidae), Central America has a great profusion of endemic species and genera, many of them very peculiar. At least one subfamily (Poeciliopsinae) is practically confined to the region, overflowing slightly into Arizona and Colombia. The most highly specialized genera, as well as some of the most generalized, occur in Central

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[17] See especially Regan (1908) for a discussion.

America, and the poeciliid fauna is richer than either the North or South American. I suspect the family to be of fairly recent origin and it seems probable that the forms now present in the southern United States are late immigrants from the south. They like warm water too much to have enjoyed Pleistocene Florida in the company of pike or muskellunge.

5. GENERAL

There is not a scrap of factual evidence, fossil or recent, on which to postulate a North American origin of the present South American fresh-water fishes. At this seemingly pontifical pronouncement, I can see some of the proponents of the northern-origin-for-everything theory cast their eyes toward that good old standby, the Green River Eocene of Wyoming. I am perfectly aware that the common occurrence of representatives of the existing South American family Osteoglossidae, and of the percomorph genus *Priscacara*, in that and other Eocene formations, has been held time and again to denote where South America got its osteoglossids and cichlids.[18] I have already said that I do not believe the osteoglossids can give us much information on the Tertiary distribution of the bony fishes, because of their age and probable wide Eocene or pre-Eocene distribution. Australia was cut off from Asia before the origin of any of the families of dominant fresh-water bony fishes, *yet it has a still living osteoglossid which is closer to the Green River Phareodus than the latter is to the living South American genera.* This single species of *Scleropages* forms the *total* living true, fresh-water, bony fish fauna of Australia and Papua and it finds its only very close relative in another living species of *Scleropages* west of Wallace's Line—and this genus is the only example of the primary division of fresh-water fishes that exists on both sides of this ancient barrier. Both species of *Scleropages* are extremely ancient relicts of the days before Ostariophysi existed. This will, I think, make it clear why I reject the mere presence of an osteoglossid in a North American Eocene formation as evidence of a northern derivation of the South American Ostariophysi.[19]

Priscacara of the Green River Eocene was described by Cope as a cichlid and is considered to be one by two students of South American fishes (Haseman, 1912; Pearson, 1937). Our foremost authority on the cichlids (Regan, 1908, p. xiv), however, decided that *Priscacara* was not a cichlid, and I agree with him. To me it seems most likely that the priscacarids were either sunfishes, as Regan (1916) decided they were, or a parallel group, now extinct, that possibly arose from the same marine ancestors as the cichlids. Moreover, even if *Priscacara* was a cichlid, it should be remembered that even today this group is not particularly averse to sea water. The genus had for its companions in the Green River lake some fishes of marine groups like *Diplomystus*,[20] gonorhynchids, and rays that frequently come up tropical rivers today. In any event, the Green River shales give us a pretty picture of the early North American fresh-water fauna before the Miocene invasion of carps.

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[18] See especially Matthew (1915, p. 298). Matthew's reasoning, and information, is here very faulty. *Lepidosteus*, which he in some way imagined to be a Neotropical group, is Holarctic. *Arius* is a marine ariid not related either to the South American pimelodid *Phractocephalus* or to *Rhineastes* of the Bridger, which belongs with the living North American Ameiurids (see Regan, 1922).

[19] Fossil osteoglossids are known, outside the Green River, from the probably Eocene *Mergelschiefer* (Sanders, 1934) of Sumatra (*Musperia* and *Scleropages*). *Brychaetus* is known from the marine Eocene London Clay and may not be an osteoglossid.

If the South American fishes did not come from North America, where did they originate? The Ostariophysi in particular certainly had a common origin somewhere. I must confess that I do not know, nor do I believe that anyone can unravel the history of this order without the fossil evidence still locked in pre-Tertiary rocks. Without this evidence, speculations on the earlier dispersal of the order are useless. Naturally, it can be argued that all we have against the early presence of South American groups in the north is negative evidence, but if the southern families never existed in the north, negative evidence is all we can expect to find there. Moreover, the Tertiary record of North American fishes is not a blank, and if characins and similar old and aggressive groups were present in North America during any part of the Tertiary, it is exceedingly strange that not a single fossil has come to light. There is every probability that most of the dominant endemic South American ostariophysan families are at least as old as the Eocene, and if they were present in North America at one time, some remnant of them ought to show up in such formations as the Green River. The European and Asiatic fossil evidence of the northern origin of the older African fishes is as nonexistant as the North American.

Eigenmann, the most eminent student of the South American fishes, believed that there was a very definite pre-Tertiary continental connection between South America and Africa, to account for the similarities plainly seen in the characins, cichlids, nandids, and others, but I cannot accept his gigantic land bridge (or some of his South American paleogeography) without better geological evidence than I have seen. Regan (1922) postulates a somewhat similar bridge.

One fact alone prevents me from believing in a wide, open, continental connection across the South Atlantic during the life of the present South American and African families of fresh-water fishes. I have mentioned the occurrence in Africa of a most remarkable assemblage of undoubtedly old families of isospondylan teleost fishes, to say nothing of the vastly more primitive bichirs; I cannot but believe that these were probably present in Africa before the cichlids, carps, or characins. If there has been a wide Tertiary or even late Cretaceous bridge across the South Atlantic, why do we find not a single, solitary representative of any of them (save again the osteoglossids) in South America? I refuse to believe that competition in South America could have killed them off; they have survived just as acute competition in Africa.

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[20] The rough-backed Eocene herrings of the genera *Diplomystus* and *Knightia* have living marine relatives on the coasts of Chile (*Ethmidium*) and Australia (*Hyperlophus*). *Diplomystus* should not be confused with the Chilean fresh-water *Diplomystes*, the most primitive known catfish.

If we are to have a South Atlantic bridge in the late Cretaceous or earliest Tertiary, the only kind I can conceive as fitting the requirements of the fishes is one like Willis's (1932) Brazil-Guinea isthmus in the Atlantic, and from Schuchert's data, it may have still been partly in existence up to the very end of the Mesozoic. If our fishes were present in the earliest Eocene, they may have been there at the end of the Cretaceous. Such a narrow isthmian connection, with its short, swift rivers, would not provide a broad highway for all the fresh-water fishes, but it would allow to pass the very same aggressive types that are now held in common by Africa and South America. The lowland, slow-water mormyrids, pantodonts, kneriids, and bichirs might very well be kept out of South America while more active, swift-water fishes passed. Again, the isthmus may not have been connected at both ends at the time the teleostean fishes came on the scene, and the transfer may have been alternate, or only one-way, but this seems unlikely. Any way one looks at it, the weak little lowland nandids, present in both continents, are problematic if one supposes a bridge that excluded mormyrids.

In any event, the fish evidence indicates there has been no South Atlantic connection since the Eocene. I have carefully compared the entire external anatomy and osteology of the African and South American characins that are supposed to show the closest intercontinental relationship (the African *Brycinus* and *Alestes* and the American *Brycon*). My conclusion is that both the African and American fishes are closely similar only because each is a generalized, dominant, and aggressive animal of a type that has probably changed little since the more modern types of characins originated. Moreover, in my studies of the cyprinodonts (Myers, 1931) I have compared the difficult-to-separate South American *Rivulus* and African *Aphyosemion*, They both belong to a rather specialized group of genera (the tribe Rivulini), and are undoubtedly closely related, but it should not be overlooked that they belong to the secondary division of fresh-water fishes, and that a fortuitous marine dispersal of one or more species at some time in the Tertiary is not impossible, particularly if a Brazil-Guinea ridge remained for a time as an island chain.

What I have said will, I believe, make it clear that our present knowledge of the fishes very distinctly favors a late Mesozoic or very early Tertiary South Atlantic land connection and makes a direct northern origin of at least the South American ostariophysans seem exceedingly unlikely. But I refuse to take a definite stand on these questions. It would be extremely presumptious, on the basis of the fishes alone, to attempt a flat contradiction of the Holarctic dispersal of the mammals, reptiles, and amphibians so ably advocated by Matthew (1915), Noble (1925), and Dunn (1923 and 1931). Our knowledge of fossil fresh-water fishes, especially in South America and Africa, is very meager and I realize how quickly the discovery of critical fossil evidence might change the picture. However, I do believe that, fossils aside, the real fresh-water fishes offer better, clearer, and vastly more conservative continental zoogeographical evidence than any one of the classes of quadrupeds, and their basic classification is far better understood than that of the frogs and perhaps of the reptiles. The mammals take precedence only because of the more abundant fossil record. My chief contention is that the proponents of Holarctic dispersal have given too little attention to contrary conclusions in other groups and have, perhaps, ridden along on the coattails of the mammal evidence a little more easily than the evidence of their own groups actually warrants.

The true explanation of the apparent conflict between the fish and quadruped evidence may lie in a direction that I have not seen pointed out. If the epi-Mesozoic interval were a time of great uplift and denudation, of longer continental duration than generally supposed, it may have been long enough for the differentiation of characins and other primitive ostariophysans in the north, the southward dispersal of a few types of ancestral bagrid-pimelodid catfishes and generalized characins into Africa and South America, and the extinction of these in Holarctica. We do know that much of the record of this period has been lost. But this is pure speculation, and, in the words of Regan, "The * * * view that Ostariophysi originated in the north and spread southwards, involves so many improbabilities as to be almost unbelievable."

Returning to the North American fishes, it may be said that there is no particular argument about them. They, at least, seem to have originated in the north, either in North America or the often-connected Eurasia. The South American ones are a problem, and I leave them thus, up in the air, so to speak, for it will be remembered that I promised to come to no conclusions.

WEST INDIAN ZOOGEOGRAPHY[21]

The geological history of the land and fresh-water vertebrate animals of the West Indies before the Pleistocene is still almost unknown. It is therefore pertinent to point out that finely spun schemes of distribution based entirely on the living (or Pleistocene) fauna are likely to receive rough treatment when and if good fossil evidence is found. What is known of the fresh-water fishes of the islands, though instructive, will of itself answer no important question conclusively, and I shall therefore give only a brief and very sketchy summary of one or two of the problems which the fishes may help us to solve.

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[21] I am entirely incompetent to handle the invertebrate evidence and have not referred to it.

Much has been published on West Indian zoogeography. For my purposes, I refer only to Matthew (1915 and 1916), Barbour (1914 and 1916), Anthony (1918), Scharff (1922), Schmidt (1928), and Dunn (1934). From the bibliographies of these papers some idea of the other literature may be gained.

Except for Matthew, most of these writers are rather definitely in favor of a union of the Greater Antilles at some time during the Tertiary, and a continental connection of this mass or one of its elements with the North, Central, or South American mainland at some period from the late Mesozoic to the middle Tertiary. I admit that the evidence these men present is both enticing and impressive. The distribution of the amphibians is the most impressive to me, perhaps because I am more familiar with that group than with other quadrupeds. Since the time of Darwin the natural occurrence of amphibians on an island has been almost universally accepted as incontrovertible evidence that that island has had a continental land connection. Amphibians are delicate creatures, extremely sensitive to desiccation and to salt water, and since they do not possess wings, it is difficult to imagine how they could possibly cross a body of sea water by any natural means. The West Indies, especially the Greater Antilles, are extremely well supplied with several genera of amphibians. Indeed it would seem that one of the chief diversions of contemporary American herpetologists is the describing of new West Indian *Eleutherodactyli!* If I am not believed, I would refer my questioner to Dr. Barbour's recent list (1935).

Against this evidence, the late Dr. Matthew has stood out practically alone in maintaining that the West Indies are true oceanic islands in that they have never had a continental connection. He holds that the entire terrestrial fauna of these islands is a waif fauna—one gained entirely through fortuitous methods of dispersal such as winds and drifting debris. It may be said that many biologists are coming to appreciate that an island can pick up an astonishing number of vertebrate and invertebrate animals in this manner. Great tropical rivers continually carry floating masses of vegetation, sometimes of considerable extent, out to sea, and all sorts of creatures are known to have been floated away to no one knows what fate on rafts of this type. It is certain that the populations of these rafts usually meet their end in rough water or storms soon after leaving the rivers, but undoubtedly in rare instances natural rafts are deposited on distant shores with at least some of their crews in a viable state. It is entirely conceivable that even tree frogs, which form the greater part of the West Indian amphibian fauna, might occasionally become unwilling sailors. Nor is it only rafts from rivers that need be considered. Almost any kind of flotsam or jetsam of any size is liable to be tenanted by some land creature, hanging on grimly, if he is able, until the sea swallows him up. The millions and millions of years of geological time surely allow enough for the (comparatively) frequent washing up of rafts on distant shores and it is beyond question that many islands have gotten their present faunas in this way. But, I will remind you, nobody has ever attempted to explain the distribution of freshwater fishes by the raft method!

Great paleogeographical interest attaches to the fresh-water fishes of the West Indies. Let us see what they tell us.

WEST INDIAN FRESH-WATER FISHES

The most striking feature of the fresh-water fish fauna of the West Indies is the complete absence of members of the primary division of fresh-water fishes, in particular the Ostariophysi, which swarm in all the waters of North, Central, and South America. Every West Indian fish to which the adjective "fresh-water" could possibly apply belongs to my secondary division or to groups still more partial to sea water. In this, the West Indies closely parallel Madagascar, where not only is the primary division entirely absent, but also the secondary ones that are present belong largely to the same systematic groups as do those of the West Indies.

To begin with, the rivers of the West Indian islands harbor a number of fishes, belonging to purely or partly marine families, which come up from the sea. There are gobies and eels and silversides and gray mullets, some of which enter fresh water only occasionally and some of which live in the rivers most of the time, returning to the sea only to spawn. One of the most conspicuous and widely-known of West Indian fresh-water fishes belongs to this category. This is the mountain mullet (*Agonostomus*), known in the Spanish islands as *dajao* or *lisa*. There are three West Indian species, the largest reaching a length of a foot, and others occur along the Caribbean coasts of South America, in Central America, and the Galapagos.[22] A related genus (*Joturus*) lives in Cuba and Central America. It is not known whether the mountain mullets return to the sea to spawn, but we do know that they belong to the marine family of gray mullets, and that they and their companions, the eels, gobies, and others, do not obey the distributional rules of true fresh-water fishes. They are of no use to us in our present problem. Neither are the two blind brotulids of the Cuban caves. They are the only known fresh-water representatives of a primarily deep-water marine family.

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[22] Regan (1908) has revised the American species.

The fishes which really belong to our secondary division of fresh-water fishes are referable to five families, the garpikes, the synbranchid eels (Synbranchidae), the viviparous cyprinodonts (Poeciliidae), and the cichlids (Cichlidae). It may be best to survey them briefly to make clear our discussion of the faunas of the particular islands.

One large garpike, *Lepidosteus tristoechus*, occurs in Cuba. It is generally supposed to be identical with the alligator gar of the southern United States, but this is questionable. If the Cuban gar is really different, it has probably been in the island a long time, but garpikes are reported to enter salt water.

Of the synbranchid eels, only one species (*Synbranchus marmoratus*) is West Indian. It is the only American form of the family so far known and it ranges from Veracruz to Argentina on the mainland. A single species of the same genus occurs in Africa and another in India; the Indian one, at least, is known to frequent brackish water.

I have already mentioned the cichlids in connection with South and Central American fishes. Three Antillean species are known, all closely related species of *Cichlasoma* (Myers, 1928; Tee-Van, 1935).

If the two records of West Indian *Fundulus* are mythical, as I believe they may be, the oviparous cyprinodonts of the Antilles belong to only three genera. *Cyprinodon* is a genus of the southern and eastern United States, northern and eastern Mexico, and certain Caribbean islands. The seaboard continental species always occur in brackish or salt water, and the inland ones are partial to the alkaline waters of desert pools. The same habits are exhibited by the island forms. *Rivulus*, on the other hand, belongs to a South American group [23] that has a general inland distribution as far north as Yucatan and the Rio Papaloapan. It has been taken in tide pools at Curaçao. The peculiar *Cubanichthys* is found only in Cuba.

The viviparous cyprinodonts form by far the largest proportion of the Antillean fresh-water fish fauna. They belong to two subfamilies, Gambusiinae and Poeciliinae, and of the first, Cuba possesses an endemic tribe composed of five distinctive genera.[24] The other Antillean Gambusiinae are all members of the widespread Central and North American genus *Gambusia*. Of the Poeciliinae there is one endemic West Indian genus, *Limia*, and three others (*Poecilia*,

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[23] See Myers (1931).

[24] See Hubbs (1924). The new Puerto Rican genus and species, *Neopoecilia holacanthus*, described in this paper, was later synonymized with *Poecilia vivipara* by Hubbs.

Lebistes, and *Mollienisia*) that are shared with the mainland of South or Central America.

The Lesser Antilles may be said to possess no fresh-water fishes at all. I hasten to say that I do not include Trinidad. That island is merely a recently separated part of the mainland. Most of its many fresh-water fishes are specifically identical with Orinoco and Guiana species, and those that now appear to be peculiar may confidently be expected to turn up when the Orinoco delta is carefully fished. All the Lesser Antilles that have sizable streams seem to have the semimarine mountain mullets and gobies but the only fishes that we could really call fresh-water ones in the whole chain are two poeciliids, the "guppy" or "millions" (*Lebistes*) and *Poecilia vivipara.* The latter is recorded from Martinique and the "guppy" from St. Lucia and Barbados. It is probable that both occur in other islands of the Leeward group, but I am not wholly convinced that these two tiny and very prolific fishes were not introduced by man. In late years the "guppy" has been spread far and wide in antimalarial work. Both are admirably fitted for waif distribution through windstorms or even actual navigation of small stretches of ocean. They are tiny lowland fishes of the fresh-water tidal belt, and on the continent never occur far from the coast. I have observed their hardiness in strong salt water in aquaria on several occasions, although they cannot exist for any very extended period in sea water. The deposition of one pregnant female in an island stream would soon fully populate that island. It is therefore evident that there is no fish evidence to support a claim of continental union of the Lesser Antilles, or to give us a hint of the histories of individual islands.

The Virgin Islands, so far as fresh-water fishes go, belong zoologically with the Lesser Antilles; there are no fresh-water fishes. A *Fundulus* has been described from them by Fowler from the old van Rijgersma collection, but the specimens are only doubtfully distinct from a common North American brackish water killyfish (*Fundulus hereroclitus*). If a *Fundulus* of this type were really present, it should have spread throughout a good part of the Antilles.

Cuba has the most distinctive fauna.[25] There are the garpike and *Synbranchus*, neither of which is known from any of the other islands. A distinctive cichlid, related rather closely to several species in southern Mexico, is very common. Among the oviparous cyprinodonts there is one *Rivulus*, related to Central American forms, and one or two subspecies of a *Cyprinodon* which is common in brackish water in Florida. The most interesting member of the group is the little endemic *Cubanichthys cubensis* which finds its only near relative in the Florida fresh-water cyprinodont *Chriopeops goodei.* With the gar and *Cyprinodon*, this forms the only element in the entire West Indian fresh-water fish fauna that points toward a North American connection. *Cyprinodon* certainly came by sea or wind, and the gar is not really good evidence until we know more about it. I consider that the weak little *Cubanichthys* and *Chriopeops*, forming by themselves a group not particularly close to other genera, may have had relatives, now extinct, in Central America. The most striking element in the Cuban fish fauna are the five genera which form the poeciliid tribe Girardinini.[26] They form a very distinctive group, distantly related to Central American types, and must have arisen in Cuba a long time ago. *Gambusia*, with two Cuban species, belongs to the same subfamily, but to a widespread tribe. There is one Cuban *Limia*, a West Indian genus of another subfamily.

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[25] See especially Eigenmann (1903). Eigenmann's several forms of Cuban cichlids have been synonymized by Hubbs (see Myers, 1928). Hubbs (1924) has revised Eigenmann's classification of the viviparous poeciliids ,and more recently (1934) described the peculiar *Quintana*, now known from both Western Cuba and the Isle of Pines. Further revisional work by Dr. Hubbs and Dr. Howell Rivero is in preparation.

Hispaniola (Haiti and Santo Domingo) has only cichlids and cyprinodonts.[27] The single well-known cichlid is almost identical with the Cuban one; a doubtful species (not yet named) is known from a single specimen. But there is a fossil cichlid from the Miocene differing from the common living one only by a couple of vertebrae—the only fossil of the present Antillean fresh-water fishes yet discovered. It would seem, therefore, that cichlids have been in Hispaniola since the Miocene. The only oviparous cyprinodonts reported from the island are a large *Cyprinodon*, living in the Haitian salt lakes, and a *Rivulus* based on one specimen captured under peculiar circumstances on Saona Island off the southeast coast. The viviparous forms belong to the ubiquitous genus *Gambusia*, to *Limia*, which is known outside Hispaniola only by the Cuban and Jamaican species, and to *Mollienisia*, a genus known elsewhere only on the mainland. There are three *Gambusias*, related to Cuban and Jamaican species. *Limia*, with eight species in the island, probably originated there; it is close to *Poecilia*. The Hispaniolan *Mollienisia* is an isolated form, not at all close to the Florida one, and perhaps finds its closest relationship in the species of the coast of Colombia or Panama.

Jamaica has only viviparous cyprinodonts. Single old records of a South American catfish and a Central American cichlid are probably mistakes, but I should not be surprised to see a real cichlid turn up there. The cyprinodonts are four *Gambusias* and two *Limias* related to Hispaniolan ones.

Grand Cayman has one *Gambusia*.

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[26] Hubbs (1924 and 1934).

[27] See Tee-Van (1935) and Myers (1928 and 1935).

Puerto Rico is the most remarkable of the Greater Antilles. In spite of the fact that its higher vertebrate fauna is very comparable to that of Hispaniola, its sole and only fresh-water fish is the viviparous cyprinodont *Poecilia vivipara,* which is common in South America and the Leeward Islands. That this strange absence of anything we might expect is real and not merely apparent is shown by Dr. Hildebrand's recent extensive survey of the Puerto Rican streams.[28] I am strongly of the opinion that the *Poecilia* got there by fortuitous means, or by the hand of man. Many years ago Cuvier and Valenciennes described a *Fundulus* from Puerto Rico, but it has remained known from the single type specimen in Paris, since the other type specimens were shown to be a *Gambusia.* I do not believe that a *Fundulus* exists in the island. Where Nichols (1929) got his figure of it I cannot say.

WHAT DO THE ANTILLEAN FRESH-WATER FISHES INDICATE?

It is difficult to say just what the fishes indicate. The distribution of several of them is so peculiar as to suggest that their arrival has been fortuitous and not dependent on dry-land connections. *Mollienisia* in Hispaniola, *Poecilia* in Puerto Rico and the Leewards, and *Cubanichthys* in Cuba are examples in point. The arrival of one *Limia* in Cuba and the presence of scarcely different cichlids in Cuba and Hispaniola might signify ocean navigation by these fishes, and I think this not unlikely. However, the presence of girardinine poeciliids in Cuba, their absence in Hispaniola and Jamaica, and the close relationships of the Gambusias and Limias of the last two islands is instructive. I do not think Cuba and Hispaniola have been united during the probably long existence of the girardinines, but Jamaica and Hispaniola may have been. Puerto Rico, from the fish evidence, seems to have had a long separate history.

Of course the most remarkable thing of all is the entire absence of Ostariophysi in the West Indies. On the face of it, the fish evidence therefore points strongly toward a lack of any mainland connection during a considerable part of the Tertiary. Personally, I am of the opinion that some northern and a number of southern Ostariophysi have been in the process of penetration of Central America for a long time, and that their absence in the islands is significant. But another alternative must not be lost sight of. Scharff, Schmidt, and others have mentioned the fact that the land area available seems to have a direct bearing on the survival of at least parts of a land fauna—in other words that an island, through partial submergence, might become too small to permit the survival of certain species. I do not at the moment recall having seen this idea applied to the fresh-water fishes of islands, and I think it will repay us to digress a bit to discuss it.

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[28] Hildebrand (1935).

Although ichthyologists have never particularly remarked it, it is a fact that all of the primitive, relict forms of fresh-water fishes that have persisted to modern times are inhabitants of relatively sluggish (and usually large) lowland water systems. The late Professor Eigenmann overlooked this when he journeyed to the Guiana plateau in 1908 to search for possible survivors of the fish fauna of his "Archiguiana"; he found none. Changes in the physical features of mountain areas are too swift to permit survival of any except fishes that have become peculiarly adapted to life in swift water, and the few relicts of a dying race are not the ones that become adapted to such a hard life. Peneplaination of a mountain range means the extinction of the highly adapted hill-stream fishes, since (despite Regan's case of the astroblepids) evolution is not exactly reversible and specialized swift-water fishes could scarcely be expected to revert to a slow-water habitat deficient in oxygen.

The only instances I know of true relict fishes living in mountainous areas concern species existing in mountain lakes that have been elevated bodily, or which are part of a once extensive plateau lake or river system, and where the certain draining of the lake in the not far distant geological future will sound the death knell of the relict. An especially good example is seen in the remarkable fish *Chaudhuria* in the Inlé Lake, Burma.

It may be expected that a considerable proportion of a mainland fish fauna living on land masses (islands) subsequently cut off from a continent will be lowland fishes not particularly well adapted to swift water. If the island were to be partially submerged within a comparatively short geological period, the lowland fish fauna might be entirely annihilated. This would be all the more likely if the original continental connection had been so low as to permit the entrance only of lowland types and the submergence occurred before these lowland fishes had had time to evolve hill-stream types.

We do know that many of the Antilles have experienced considerable changes of elevation. Barbados in particular appears to have been very badly treated by orogenic or other forces. If we can believe the evidence of its sedimentary deposits, it sank 6,000 to 10,000 feet below the sea between the Eocene and Miocene, and in the Pliocene bobbed up again as an island. Naturally, complete subsidence below the sea would destroy the fresh-water fauna, and the Greater Antilles have experienced no such devastating changes of level, but even relatively slight subsidence might have a profound effect on the river fishes.

In spite of this, I feel confident that had aggressive Ostariophysi ever been able to reach the Greater Antilles, nothing short of almost complete submergence of the larger islands would have entirely destroyed them. Characins and carps in particular would have been especially adaptable to hill-stream life, and their vigor and fecundity, especially in the absence of competitors, would have ensured their survival under almost any natural conditions short of complete desiccation or immersion in sea water.

If this view be granted, the only conceivable continental connection of a Greater Antillean land mass is one with Central America, at a time when neither the North American nor the South American Ostariophysi had invaded much of Middle America. I have already shown that we cannot date these invasions. Finally, if we are to suppose that all the South American Ostariophysi originally wended their way southward through Central America, I believe we should have to push any such continental bridge back into the Mesozoic, if indeed it ever existed at all.

LITERATURE

ANTHONY, HAROLD ELMER.

1918. The indigenous land mammals of Porto Rico, living and extinct. Mem. Amer. Mus. Nat. Hist., n. s., vol. 2, pt. 2, pp. 331–435, figs. 1–55, pls. 55–75.

BARBOUR, THOMAS.

1914. A contribution to the zoogeography of the West Indies, with especial reference to amphibians and reptiles. Mem. Mus. Comp. Zöol., vol. 44, no. 2, pp. 209–359, 1 pl.

1916. Some remarks upon Matthew's "Climate and Evolution." Ann. New York Acad. Sci., vol. 27, pp. 1–10.

1935. A second list of Antillean reptiles and amphibians. Zoologica, Sci. Contr. New York Zool. Soc., vol. 19, no. 3, pp. 77–141.

BERG, LEO SEMENOVITCH.

1934. The suborder Esocoidei (Pisces). Izvestia Perm Biol. Sci.-Invest. Inst. Perm State Univ., vol. 10, nos. 9–10, pp. 385–391.

DUNN, EMMETT REID.

1923. The geographical distribution of amphibians. Amer. Nat., vol. 57, pp. 129–136.

1931. The herpetological fauna of the Americas. Copeia, 1931, no. 3, pp. 106–119, figs. 1–6.

1934. Physiography and herpetology in the Lesser Antilles. Copeia, no. 3, pp. 105–111.

EIGENMANN, CARL H.

1903. The fresh-water fishes of Western Cuba. Bull. U. S. Fish Comm., vol. 22, pp. 211–236, 17 figs., pls. 19–21.

1909. The fresh-water fishes of Patagonia and an examination of the Archiplata-Archhelenis theory. Repts. Princeton Univ. Expeds. Patagonia, Zoology, vol. 3, pt. 3, pp. 225–374, 1 map, pls. 30–37.

HASEMAN, JOHN DIETRICH.

1912. The relationship of the genus *Priscacara*. Bull. Amer. Mus. Nat. Hist., vol. 31, art. 8, pp. 97–101.

HAY, OLIVER PERRY.

1902. Bibliography and catalogue of the fossil Vertebrata of North America. Bull. U. S. Geol. Surv., no. 179, 868 pp.

1929. Second bibliography and catalogue of the fossil Vertebrata of North America. Carnegie Inst. Washington, publ. no. 390, vol. 1, 916 pp.

HILDEBRAND, SAMUEL FREDERICK.

1935. An annotated list of fishes of the fresh waters of Puerto Rico. Copeia, no. 2, pp. 49–56.

HUBBS, CARL LEAVITT.

1924. Studies of the fishes of the order Cyprinodontes, I–IV. Misc. Publ., Mus. Zool., Univ. Michigan, no. 13, pp. 1–31.

1934. Studies of the fishes of the order Cyprinodontes, XIII, *Quintana atrizona*, a new poeciliid. Occ. Pap., Mus. Zool., Univ. Michigan, no. 301, pp. 1–8, 1 pl.

HUSSAKOF, LOUIS.

1932. The fossil fishes collected by the Central Asiatic Expeditions. Amer. Mus. Novit., no. 553, pp. 1–19.

VON IHERING, HERMANN.

1907. Archhelenis und Archinotis. 350 pp., 1 map. Leipzig.

MATTHEW, WILLIAM DILLER.

1915. Climate and evolution. Ann. New York Acad. Sci., vol. 24, pp. 171–318, 33 figs.

1916. Supplemental note. Ann. New York Acad. Sci., vol. 27, pp. 11–15.

MYERS, GEORGE SPRAGUE.

1928. The existence of cichlid fishes in Santo Domingo. Copeia, no. 167, pp. 33–36.

1931. The primary groups of oviparous cyprinodont fishes. Stanford Univ. Publ., Univ. Ser., Biol. Sci., vol. 6, no. 3, pp. 243–254.

1935. An annotated list of the cyprinodont fishes of Hispaniola, with descriptions of two new species. Zoologica, Sci. Contr. New York Zool. Soc., vol. 10, no. 3, pp. 301–316, figs. 273–279.

NICHOLS, JOHN TREADWELL.

1929. The fishes of Porto Rico and the Virgin Islands. New York Acad. Sci., Sci. Surv. Porto Rico and the Virgin Islands, vol. 10, part 2, pp. 161–295, figs. 1–174.

NOBLE, GLADWYN KINGSLEY.

1925. The evolution and dispersal of the frogs. Amer. Nat., vol. 59, pp. 265–271.

PEARSON, NATHAN EVERETT.

1937. The fishes of the Beni-Mamoré and Paraguay basins, and a discussion of the origin of the Paraguayan fauna. Proc. California Acad. Sci., ser. 4, vol. 23, no. 8, pp. 99–114.

REGAN, CHARLES TATE.

1908. Biologia Centrali-Americana. Pisces, xxxii+203 pp., 2 maps, 26 pls.

1916. [Remarks on South American fishes and on *Priscacara*.] Proc. Zool. Soc. London, 1916, pp. 546–547.

1922. The distribution of the fishes of the order Ostariophysi. Bijdr. tot de Dierkunde, Leiden, vol. 22, pp. 203–207.

SANDERS, MARGARETHA.

1934. Die fossilen Fische der Alttertiären Süsswasserablagerungen aus Mittel-Sumatra. Verh. Geol.-Mijnbouwk. Gen. Nederland en Kolon., Geol. Ser., vol. 11, no. 1, pp. 1–144, pls. 1–9.

SCHARFF, ROBERT FRANCIS.

1922. On the origin of the West Indian fauna. Bijdr. tot de Dierkunde, Leiden, vol. 22, pp. 65–72.

SCHLAIKJER, ERICH M.

1937. New fishes from the continental Tertiary of Alaska. Bull. Amer. Mus. Nat. Hist., vol. 74, art. 1, pp. 1–23, figs. 1–7, 1 map.

SCHMIDT, KARL PATTERSON.

1928. Amphibians and land reptiles of Porto Rico, with a list of those reported from the Virgin Islands. New York Acad. Sci., Sci. Surv. Porto Rico and the Virgin Islands, vol. 10, part 1, pp. 1–160, 62 figs., 4 pls.

SCHUCHERT, CHARLES.

1932. Gondwana land bridges. Bull. Geol. Soc. Amer., vol. 43, pp. 875–916, pl. 24.

TEE-VAN, JOHN.

1935. Cichlid fishes in the West Indies with especial reference to Haiti, including the description of a new species of *Cichlasoma*. Zoologica, Sci. Contr. New York Zool. Soc., vol. 10, no. 2, pp. 281–300, figs. 269–272.

VOIGT, ERHARD.

1934. Die Fische aus der mitteleozänen Braunkohle des Geiseltales, mit besonderer Berücksichtigung der erhaltenen Weichteile. Nova Acta Leopoldina, Halle, Neue Folge, Bd. 2, Heft 1–2, pp. 21–146, pls. 1–14.

WILLIS, BAILEY.

1932. Isthmian links. Bull. Geol. Soc. Amer., vol. 43, pp. 917–952, pls. 25–29.

EXPLANATION OF PLATES

PLATE 1.

Typical North American fresh-water fishes.

FIG. 1. A carp or minnow, *Semotilus*. (From Girard, Pacific R. R. Rep.)
2. An ameiurid catfish, *Ameiurus*. (From Evermann and Kendall, Bull. U. S. Bur. Fish.)
3. A sunfish, the warmouth bass, *Chaenobryttus*. (From Girard, Pacific R. R. Rep.)
4. A true perch, the darter, *Hadropterus*. (From Forbes and Richardson, Illinois State Nat. Hist. Surv.)

PLATE 2.

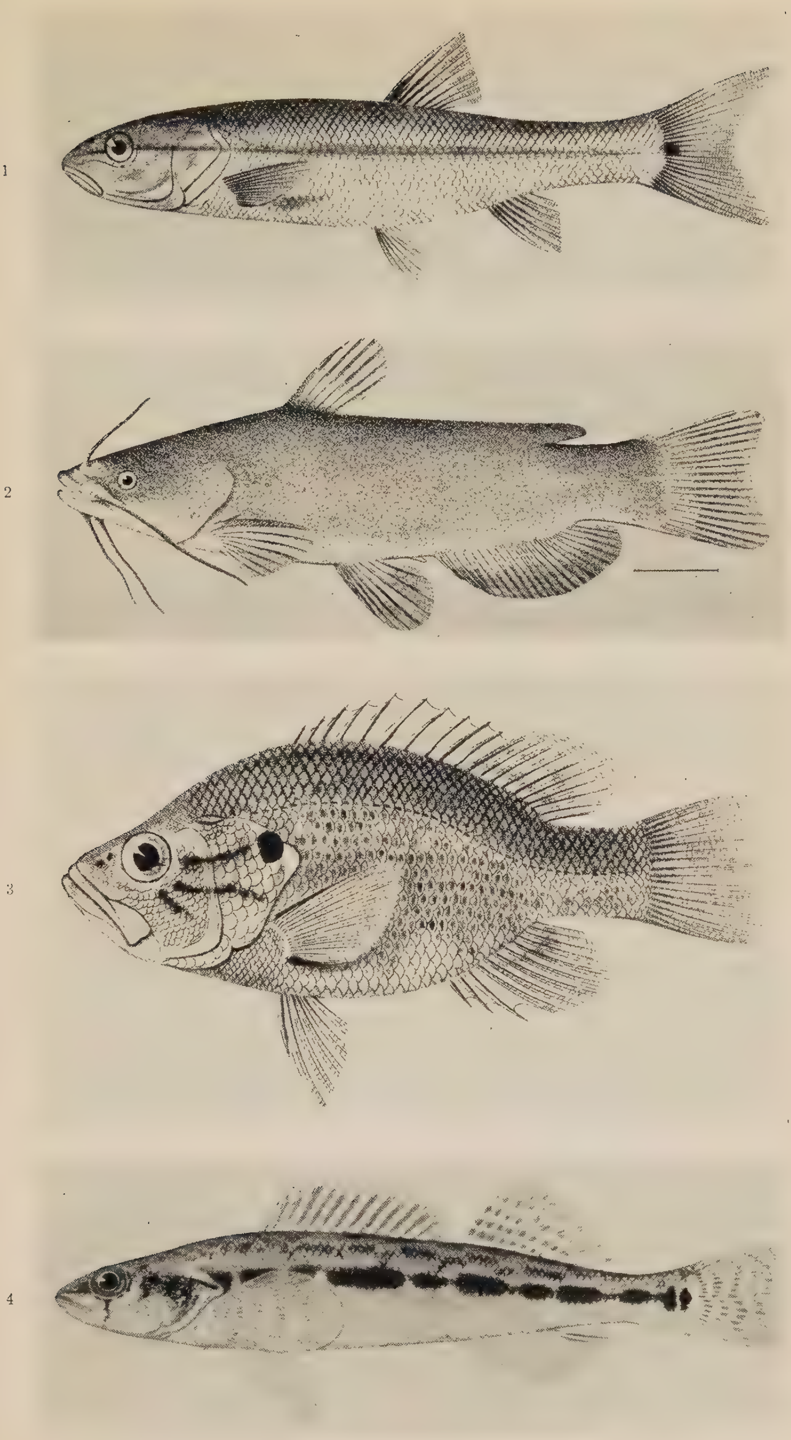
Typical South American fresh-water fishes.

FIG. 1. A generalized characin, *Brycon*. (From Günther, Trans. Zool. Soc. London.)
2. A gymnotid eel, *Adontosternarchus*. (From Ellis, Mem. Carnegie Mus.)
3. An armored catfish, or loricariid, *Plecostomus*. (From Starks, Stanford Univ. Publ.)

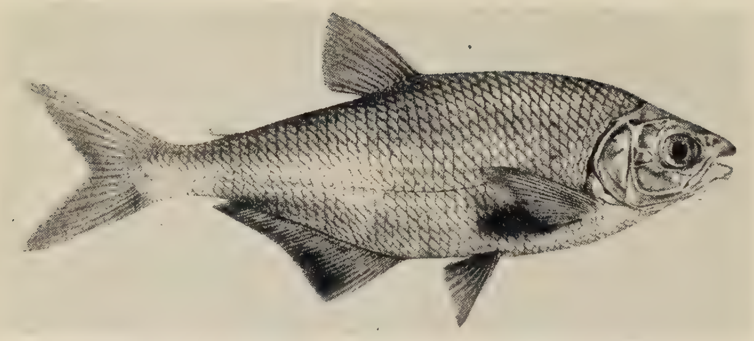
PLATE 3.

Typical West Indian fresh-water fishes.

FIG. 1. A mountain mullet from St. Vincent, *Agonostomus microps*. (From Günther, Trans. Zool. Soc. London.)
2. A viviparous cyprinodont, or poeciliid, from the Artibonite System, Haiti, *Mollienisia dominicensis*, female. (From Myers, Zoologica.)
3. The same, male. (From Myers, Zoologica.)
4. A cichlid from Source Trou Caiman, Haiti, *Cichlasoma haitiensis*. (Drawn by Mary Wallach.)



TYPICAL NORTH AMERICAN FRESH-WATER FISHES.
(FOR EXPLANATION, SEE PAGE 364.)



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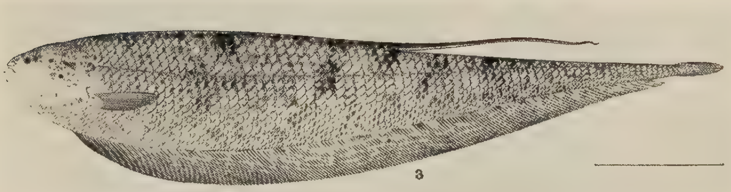

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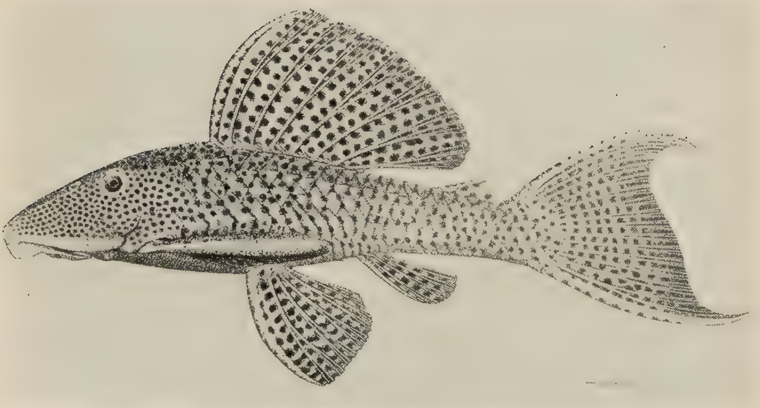

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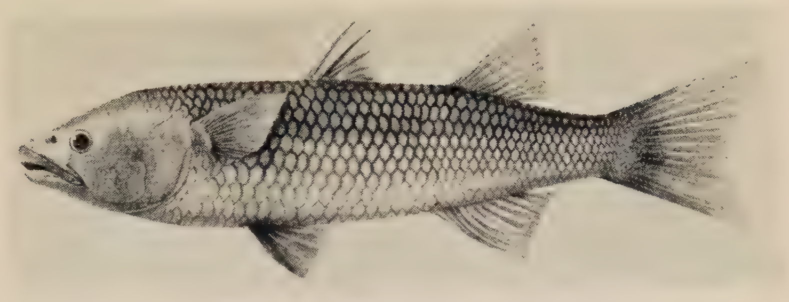
TYPICAL SOUTH AMERICAN FRESH-WATER FISHES.

(FOR EXPLANATION, SEE PAGE 364.)



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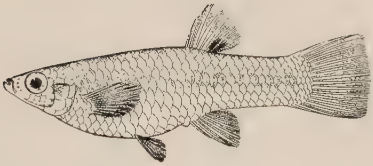

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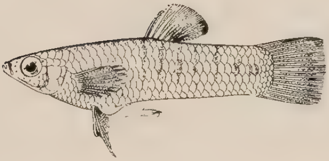

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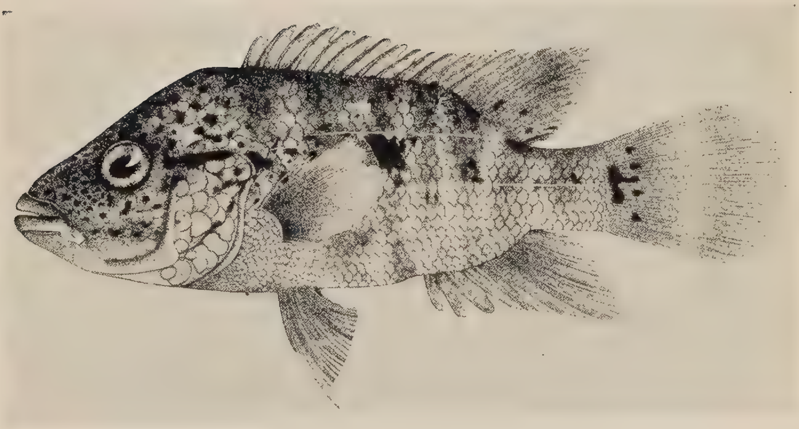

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TYPICAL WEST INDIAN FRESH-WATER FISHES.
(FOR EXPLANATION, SEE PAGE 364.)

THE BREEDING HABITS OF SALMON AND TROUT

By Leonard P. Schultz
Assistant Curator, Division of Fishes, United States National Museum

[With 5 plates]

Although salmon and trout are of the greatest economic importance in the Northern Hemisphere and have been introduced into scattered areas south of the Equator, authentic information concerning their breeding activities is not generally available. Many volumes have been written on the life histories of salmon and trout, including several popular books, nearly all of which incorrectly portray the spawning habits of this great group of fish belonging to the family Salmonidae. The technical selection and breeding of domestic animals, such as cows, horses, pigs, and chickens, is a highly specialized science now, but the selection and development of similar brood stocks of trout received little attention until recently.

The spawning migration of salmon is anadromous, or from the sea to fresh-water streams. This is the reverse of that of fresh-water eels, *Anguilla*, which have a catadromous migration, or from fresh-water streams to the sea. Those eels which live in the streams tributary to the region of the North Sea migrate westward in the North Atlantic Ocean a distance of about 3,000 miles to a location a little north and east of the West Indies. This long migration is no greater a distance than the king salmon of the Pacific travels to deposit its eggs. In the Yukon River some salmon go up the river 3,000 miles (Gilbert, Bull. U. S. Bur. Fish., vol. 38, p. 318, 1921–22 (1923)), in addition to a long migration while still in the sea. The migration of the king salmon is probably the longest of all salmon and trout; the pink salmon migrates least of all of the Pacific salmon (genus *Oncorhynchus*), since it spawns near the mouths of streams or upstream but a few miles above salt water.

In trout, genera *Salmo* and *Salvelinus*, the migratory instinct is also definitely developed, but these forms spend most or all of their lives in fresh water and thus there is no necessity of migrating so far. Other closely related families of salmonidlike fishes, such as white-fishes (family Coregonidae) and smelt (family Osmeridae), make similar migrations. Some of the smelt, however, do not enter fresh-water streams, but deposit their eggs in the fine gravel of the ocean beach among the breaking waves. But the habits of fish spawning in the ocean surf cannot be told here—that is another story.

The salmon, in their great urge to reach the proper habitat for deposition of their eggs, often wear themselves out in their attempt to navigate waterfalls or fish ladders placed in dams (pl. 3). It is said that Pacific salmon will jump vertically as much as, or more than, five to six times their length in an attempt to go over waterfalls. Sometimes this is fatal to the fish as it falls backward and strikes sharp rocks. If he is not seriously injured, upon recovery he will continue to leap until either successful in going over the obstruction or until he is completely exhausted and falls prey to birds, bears, or other predators, as he drifts downstream. The urge to go upstream is so great in both salmon and trout that they expend a great amount of their stored energy by the time they have spawned, leaving them weakened and emaciated.

This worn-out condition is not the chief cause of the death, after spawning, of the five species of Pacific salmon. Instead, they have reached the end of their life cycle, and even those fish in good condition die shortly after their reproductive period is completed (pl. 4). Trout, steelhead, (pl. 1, fig. 2) and the Atlantic salmon may spawn for several successive years before completing their life cycles.

Finally, after traversing great distances or but a few miles, all species of salmon and trout attempt to locate a particular type of stream bottom in which to lay their eggs. Their nests are built only in the gravelly or stony sections of a stream which has nearly clear, rapidly flowing water of a rather low temperature. If the fish are unsuccessful in locating these conditions, they seldom lay their eggs and may die instead. There is evidence, too, that the great majority of Pacific salmon, as well as some species of trout, seek and usually find the stream in which they grew up as babies, even though a few intervening years were spent in the far-away sea and entirely outside the influence of the "parent stream" (Davidson, Science, vol. 86, pp. 55–56, 1937). This is known as the "homing" instinct of salmon and trout and is often referred to under the name "parent stream theory."

The time of the year when salmonids migrate and lay their eggs is highly variable. Pacific salmon spawn any time from March to December, depending on the locality and the species. Steelhead, or rainbow trout, spawn in late autumn and winter, or in certain regions in the early spring. Cutthroat trout typically are spring spawners. The Atlantic salmon, eastern brook trout, western dolly varden, lake trout, and brown trout, all breed in the autumn.

These species may be observed to build nests and perhaps spawn by anyone who has the patience and time to study such activities. The observer should cautiously approach the gravel riffles in which saucerlike depressions, 1 to 4 feet in diameter, have been excavated and where trout occur during the spawning season. If he remains very still, in 5 to 20 minutes the breeding salmon or trout will swim back over the riffle where they were when the observer first made his appearance. These fish may stay a moment, then leave for the deep hole again, usually above the riffle, where they hide for some time before again venturing out. However, if all is still and quiet after one or more such attempts, the spawning salmon or trout will remain on the riffle, nearly oblivious of the presence of the spectator. If the observer should make sudden movements they dart away, and then he must wait for them to return and again become accustomed to his presence. It is possible to become so much a part of the environment that the observer "can even stand astride one of the nests, while the male and female redfish pursue their normal activities" (Schultz and Students, Mid-Pacific Magazine, January–March 1935, p. 69).

The spawning salmon and trout usually segregate themselves in pairs, although an extra male may be present in certain species (rainbow) during the spawning act. Each of these pairs remains over a certain area in the stream bottom which it defends. This area becomes the nest, or redd, in which the eggs are laid. Since the nest-building activities are practically the same for all species of salmon or trout, the following account of the activities of the little redfish, the landlocked sockeye salmon, *Oncorhynchus nerka*, is given from personal observations (pl. 1, fig. 1).

NEST-BUILDING ACTIVITIES

A pair of redfish usually engage in normal nest building when unmolested by other fish. If the pair is alone, the female may let herself drift over the lower center of the redd, where she will turn over on her side and vigorously flex her tail four to six times against the bottom, as this motion carries her a foot or more upstream. The tail of the fish during these movements comes in contact with the bottom, and vigorous hydraulic forces are set up by the upward movement of the tail, which lift the gravel and sand off the bottom. The material thus disturbed is carried by the swift current downstream, the smaller particles farthest and the larger stones but a few inches before they settle. The female may return to the starting point and repeat this nest-building act (fig. 1). If undisturbed, she may in 20 minutes complete as many as 70 separate nest-building acts with an interval between them of as little as 4 seconds or as long as 1½ minutes. On the average, females turn, with almost equal frequency, either their left or right side toward the stream bottom.

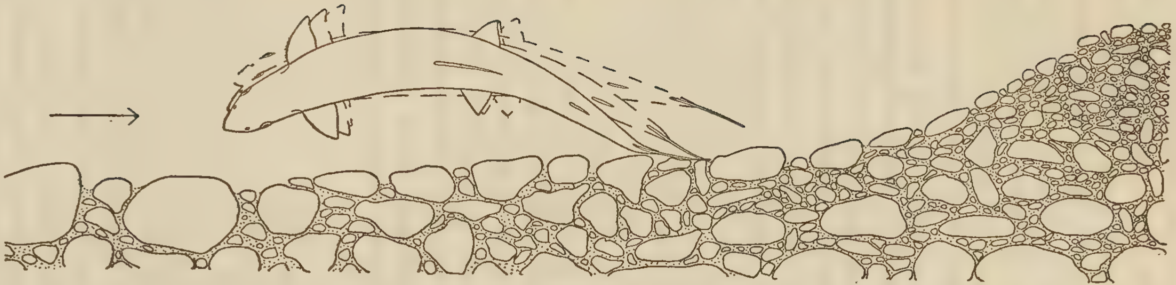


FIGURE 1.—The nest-building act. A diagram of a silver salmon, *Oncorhynchus kisutch*, 14½ inches long, from near Seattle, Wash. She is just starting the upward stroke of her tail which creates currents that lift the stones and sand off the bottom. These are carried by the downstream flow of the water (the arrow indicates the direction of flow), and accumulate into a small mound just below the excavation. Drawn to scale by Clinton E. Atkinson, Don Earnest, and Robert Meigs, former students of the author.

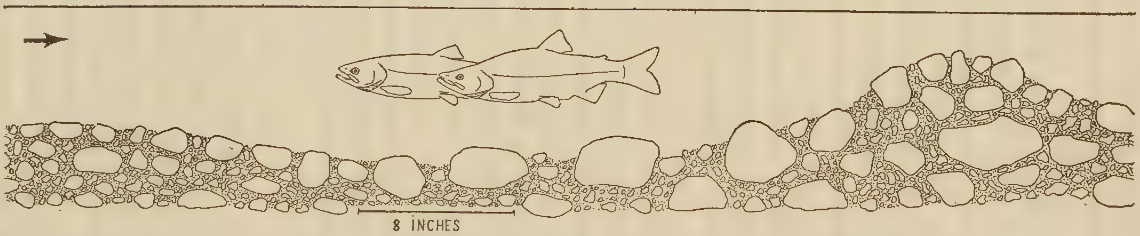


FIGURE 2.—**A diagram illustrating the relative position over a nest of a pair of little redfish, *Oncorhynchus nerka*, during their vibratory courtship act.** Drawn by Dan Merriman. Courtesy Mid-Pacific Magazine.

A review of the literature describing the nest-building activities of salmon and trout indicates that practically all the older accounts have confused it with the spawning act, the latter an entirely different behavior. The following authors, among others, have given the same interpretation to the nest-building act as described above: White (1930, pp. 103–107) on eastern brook trout; Greeley (1932, pp. 242–243) on brook, brown, and rainbow trout; Hazzard (1932, p. 345) on eastern brook trout; Schultz and Students (1935, pp. 71–72) on landlocked sockeye salmon.

The process of nest building, the most obvious activity over the nest, is done mostly by the females, although now and then certain males flex their bodies three to five times, while other males never participate in the construction of the nest. Usually during the 2 to 4 seconds that it takes the female to flex her body for purposes of disturbing and lifting the gravel so that the current carries it downstream, the male, if present, stands by inactively near the lower part of the nest. The time that it takes to construct a single nest-pit varies considerably with the individual, taking but a few hours or a few days.

In the case of breeding salmon and trout, the careful observer has little difficulty in distinguishing the two sexes, because the breeding male is usually more highly colored than the female, and his body is compressed (sides flattened), that of the female more rounded. Often the snout is somewhat arched in the male trout and definitely hooked (pl. 1, fig. 1) in the male of Pacific salmon; the female's snout is normal. Experienced fish-culturists are able to tell the sex of spawning salmonids by feeling of them with their hands, the males having on the underside of the abdomen two hard ridges which are lacking in females.

The completed nests of salmon and trout are saucerlike depressions with a small mound of sand and gravel on the downstream side. Their depth and size depend on the size of the individual that constructs the nest, and their shape on the rate of flow of the water over the nest. Nearly round depressions occur in slowly moving water and oblong-oval nests where the current is rapid. A fish about a foot long builds a nest from 2 to 4 inches deep, depending on the type of stream bottom. In moderately flowing water the width of the nest is one or two times the length of the owner, and the length of the nest is two or three times that of the female which excavated it. The mound of sand and gravel at the lower end of the nest lies from 1 to 3 inches above the average level of the stream bottom and extends downstream below the depression 2 or 3 feet. Several of these nests, or redds, may occur in the same riffle of a stream. In the case of large king salmon, a single nest may occupy several square yards of the stream bottom.

The nests are continually changing, because after the female deposits a portion of her eggs, she covers them with gravel, and as she progressively excavates one or more new nests upstream, some of the excavated material of the new locations covers the eggs in the older nests deeper and deeper—a real conservation of energy. Several batches of eggs may be deposited before the female has completely deposited all of her ova; sometimes, however, a female may select an entirely new location for her next nest.

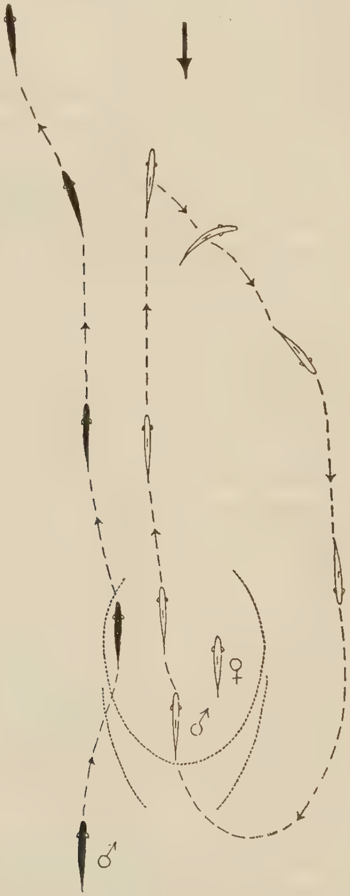


Figure 3.—A diagram illustrating the escorting act of the male redfish, *Oncorhynchus nerka*. Note that the female, ♀ (dotted) remains over the nest while the male, ♂, drives the invader (solid black) away. The male and female are shown in their positions over the nest. Drawn by Dan Merriman. Courtesy Mid-Pacific Magazine.

DEFENSE OF THE NEST

Both male and female defend their nest against invading fishes by rushing at them or by the male escorting the intruding male upstream or to one side. Sometimes the defender in his rush at an invading fish catches his teeth in the abdomen near the pelvic fins of the invader, and before he can loosen himself the two drift downstream some distance. The defender usually returns to his nest and immediately takes up his position over, a little behind, and to one side of the female. The female usually defends the upper portions of the nest, while the male defends the nest from invaders coming in from any direction. Both drive away either a male or female upon their approach unless fish much larger than themselves swim into the nest. When this happens, often a new male takes possession, and breeding activities continue with little interruption.

Sometimes when an invading male approaches, he is escorted away by the male owner of the nest (fig. 3). In the case of the little redfish, a landlocked salmon, the defending male may swim out to meet him, often elevating his dorsal fin. If the intruder does not retreat, the defender will swim slowly toward him, and when about a foot or so away, he will turn so that the two fish are nearly parallel, and they then proceed slowly upstream, sometimes as far as 10 feet before the invader either goes his own way, or makes a dash for the nest. Should the latter happen, the escorting act might occur again. In general the male occupies much of his time in driving away other males, and the female drives away invading males or females. Should the invading male be successful in driving away the original owner, the former now takes possession. Several males usually pair off with the female owner of a nest before she has laid all of her eggs.

Other activity besides the defense of the nest may occur in the immediate vicinity, since unpaired and paired males continually chase each other about both below, among, and above the area occupied by the redds, or nests.

COURTSHIP ACTIVITIES

Between many of the nest-building acts of the female redfish as she drifts back into the center of the nest during recovery and assumes a normal position over the center of the nest, the male usually approaches her from behind and a little to one side. He will just touch his head or snout to her body in the region between the adipose fin and the pectorals, gently move his body toward and against hers, at which moment he will vibrate, or quiver, vigorously for a second or two. He will partially erect his dorsal fin near the end of this act (fig. 2). The female usually remains perfectly still, although once in a while she too will quiver in unison with the male. No eggs or milt have ever been seen in the water during this courtship act, thus indicating that no actual spawning occurs. Time and time again the male repeats this courtship act, if no intruder interrupts, as often as every 5 to 10 seconds or at longer intervals. Other courtship acts occur, too. Frequently the male will swim back and forth over the female when she is resting near the bottom of the nest, often touching her dorsal fin with his body and fins. Another recognizable courtship behavior is an act of nudging. The male gently swims up to the midside of the female while she is over the bottom of the nest and nudges her in the side with his snout. These acts of courtship of the salmon and trout have been observed by various authors among whom may be mentioned: Milner (1874, pp. 52–54), vibratory courtship act in brook trout; Hazzard (1932, p. 345), nudging and side-to-side swimming over the female for brook trout; Greeley (1932, pp. 242–243), nudging and side-to-side swimming over female for rainbow trout; Needham (1934, pp. 334–335), nudging and quivering in steelhead trout (pl. 5). Similar courtship activities have been observed by the author in the landlocked sockeye salmon, silver salmon, king salmon, and cutthroat trout (pl. 2).

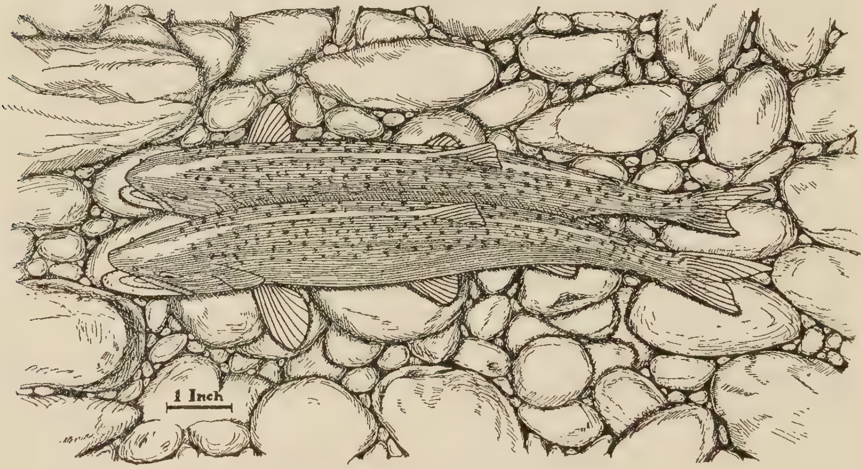


FIGURE 4.—A diagram of the spawning act of the little redfish, *Oncorhynchus nerka*. Male (lower) and female (upper). The positions of the fins were not seen, but it is supposed that they were spread against the rocks below, enabling the fish to maintain their positions in the current. Drawing made by Arthur Welander from preserved fish placed in the approximate spawning positions observed by Dan Merriman and Arthur Welander. Courtesy Mid-Pacific Magazine.

THE SPAWNING ACT

Among the large number of papers written on the habits of salmon and trout, but few authors have definitely described the spawning act and those only within the last 10 years. All others have either not seen it or have more or less confused it with the nest-building and courting acts, from which it may be concluded that the true spawning act is seldom seen. No doubt this confusion and the lack of accurate observation for so many years was caused by the great authority and weight of opinion of certain older ichthyologists, who perhaps exerted too much influence on their students and blinded their eyes to the exact methods of egg laying and fertilization. Recently, observations by Greeley on rainbow trout, Hazzard on eastern brook trout, Belding on the Atlantic salmon, Schultz and Students on the little redfish, a landlocked sockeye salmon (fig. 4), and Needham on the steelhead, all indicate that the details of actual egg laying are essentially the same for the various species. The spawning act or egg-laying act may be summarized as follows from Needham's (1934, pp. 334–335) account for the steelhead:

> The female dropped back in the center of the pit with her vent and anal fin well down in the deepest part. The male instantly moved into position parallel to her. Their vents were opposite and, since he was considerably shorter, his head came only about to her pectorals. Both fish opened their mouths wide, the female particularly was seen to arch her body, raising her head so that the tip of her snout was out of water. Eggs and milt were exuded with a quivering motion by both fish at exactly the same instant. The snout of the female, where it protruded from the water, was seen to cause ripples on the surface from the quivering motion as the eggs were deposited. The white cloud of milt partially obscured the eggs from our view, but we could clearly see the stream of bright pink eggs dropping into the bottom of the nest. They appeared to stay in a very compact group and none were observed floating from the nest. The milt settled in a more or less compact way about the eggs, though some of it was carried away by the current. The whole process did not require much more than 2 seconds. The male during this process was on the left side of the female as she faced upstream. The female remained in a vertical position. The male inclined slightly toward and appeared to be in definite contact.

FERTILIZATION AND WATER-HARDENING

Both eggs and milt are discharged at the same time during the spawning act, and Nature has so beautifully coordinated each step in the breeding activities of salmon and trout that the eggs or ova are fertilized the instant they are shed; otherwise they would probably not be fertilized at all because the sperm would be carried by the current downstream away from the nest. The millions of spermatozoa making up the milt are inactive until they enter the water, then for about 45 seconds they swim about with great rapidity, but by the end of 1½ minutes all have become inactive and probably many have died. The eggs, once they enter water, change rapidly too. For about 1 minute after the eggs are in water it is possible for nearly 100 percent of them to be fertilized when active spermatozoa are present, but at the end of another 4 minutes in the water the shell of the egg has so changed that it is nearly impossible for a spermatozoan to enter. All spermatozoa must enter fish eggs through a single minute pore, the micropyle, in the egg membrane or outer shell of the egg and after one spermatozoan has entered (it takes but a single spermatozoan to start the development of the egg) it is impossible for another one to do so. Should no sperm enter the egg within the first few minutes that the egg is in the water, the micropyle closes, and that egg can never be fertilized because "water-hardening" has already begun.

"Water-hardening" is a physiological process by which water passes through the egg membrane (outer shell of the eggs) into the space below it. This space between the yolk and the egg membrane is called the perivitelline space. The eggs of all salmon and trout swell up about one-third larger in size than when first laid (fig. 5), and the outer shell becomes so tightly stretched that the eggs are rigid and, when dropped, may bounce like rubber balls. The egg membrane is adhesive when first laid, but at the end of about three-quarters of an hour, after the completion of water-hardening, it is smooth and no longer sticky. This adhesive quality causes grains of sand to adhere to the eggs which helps to keep them in the bottom of the nest until they are covered with gravel by the female.

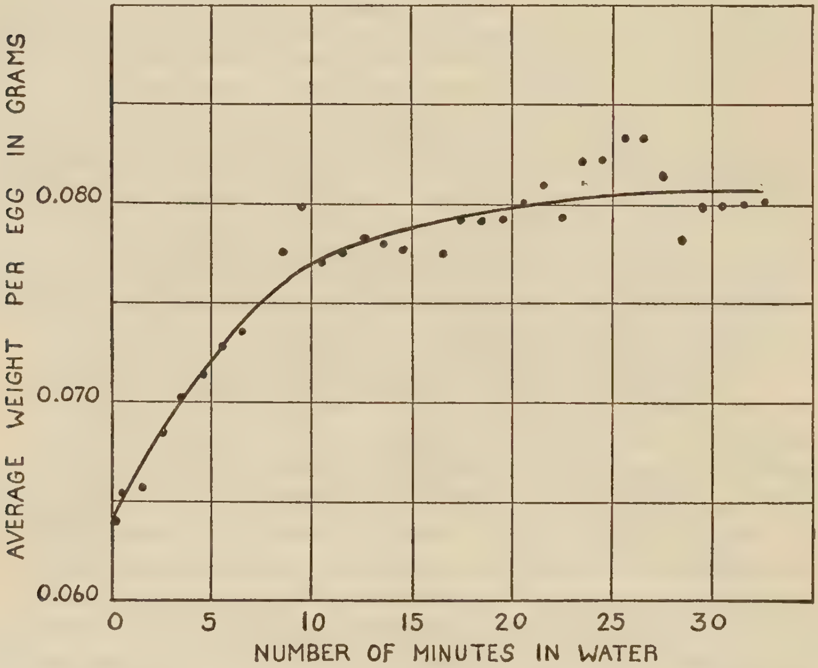


FIGURE 5.—The rate of increase in weight (water-hardening) of the eggs of the little redfish, *Oncorhynchus nerka*. The eggs from six females were used in six different experiments. All weights were converted into comparable terms and are expressed as the average initial weight of all eggs from the six females. This was necessary because the eggs in different females vary greatly in size and weight. Each black spot on the graph represents an average determined from about 70 eggs. The average initial weight was 0.0645 gram per egg.

POST-SPAWNING ACTIVITIES

Within a few minutes after the eggs are laid and fertilized during the spawning act, the female turns on her side and begins to cover them in the same manner that she excavated the nest. This is accomplished not by digging into the pit where the eggs occur, but slightly upstream, so that the current sweeps the disturbed material over the eggs.

Usually the eggs are well covered within an hour or two to a depth of 2 inches or more. This post-spawning behavior offers distinct advantages for the protection of the eggs and recently hatched fry, as pointed out by Needham (1934, p. 336) who says: "Eggs laid in the first portions of the nest are gradually buried deeper and deeper by materials being washed downstream from pits dug above as she works upstream." The eggs remain in the nests covered with gravel until hatched. The oxygen supply needed by the eggs and young trout during their development in the gravel is supplied by the seepage of water through the loose material of the stream bottom. The time required for the eggs to hatch depends on the species as well as on the water temperature. Eggs laid in cold water take longer to hatch than those laid in warmer water, the time varying from 2 or 3 weeks to 6 or 8 months. The baby salmon or trout after hatching remain in the gravel until their yolk sack has been absorbed, then they gradually make their way through the gravel into the water of the stream.

DESTRUCTION OF EGGS

The eggs, after being covered by the female, are relatively safe from predatory animals. However, when first laid, some may be swept from the nest pit by the current. Should any of these escape the mouths of fish lurking in the vicinity ready to eat them, they would never develop for they would be carried to the pools below, where the eggs would settle to the bottom, gradually becoming covered with sediment that would cause them to be suffocated. Other hazards await the eggs. Fungus often attacks them and may spread through the nest when the eggs are too crowded, but it can make little headway when they are well separated. Freshets often wash out the eggs of the salmon and trout, and once they are removed from the nest they have little or no chance of survival. In certain areas the streams recede after the trout have spawned, leaving the nests high and dry, which soon kills the eggs. These, among other dangers, take their toll of the new crop of eggs and young fish planted so carefully by the mother.

LITERATURE CITED

DAVIDSON, FREDERICK A.
1937. "Migration" and "homing" of Pacific salmon. Science, vol 86, pp. 55–56.

GILBERT, CHARLES HENRY.
1923. The salmon of the Yukon River. Bull. U. S. Bur. Fish. 1921–1922, vol. 38, pp. 317–332, figs. 274–300.

GREELEY, JOHN R.
1932. The spawning habits of brook, brown, and rainbow trout, and the problem of egg predators. Trans. Amer. Fish. Soc., vol. 62. pp. 239–248.

HAZZARD, ALBERT S.

1932. Some phases of the life history of the eastern brook trout *Salvelinus fontinalis* Mitchell. Trans. Amer. Fish. Soc., vol. 62, pp. 344–350.

MILNER, JAMES WOOD.

1874. Habits of the brook trout during the breeding season. Rep. U. S. Comm. Fish. 1872–1873, pp. 52–55.

NEEDHAM, PAUL R.

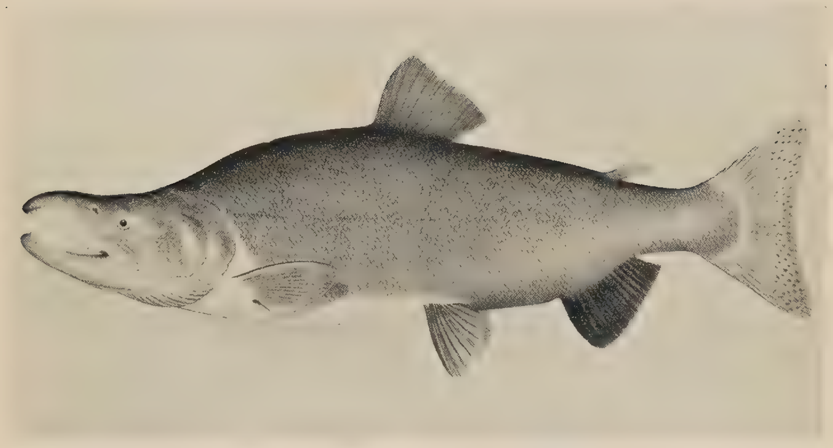
1934. Observations on the spawning of steelhead trout. Trans. Amer. Fish. Soc., vol. 64, pp. 332–338, figs. 1 and 2.

SCHULTZ, LEONARD PETER, AND STUDENTS.

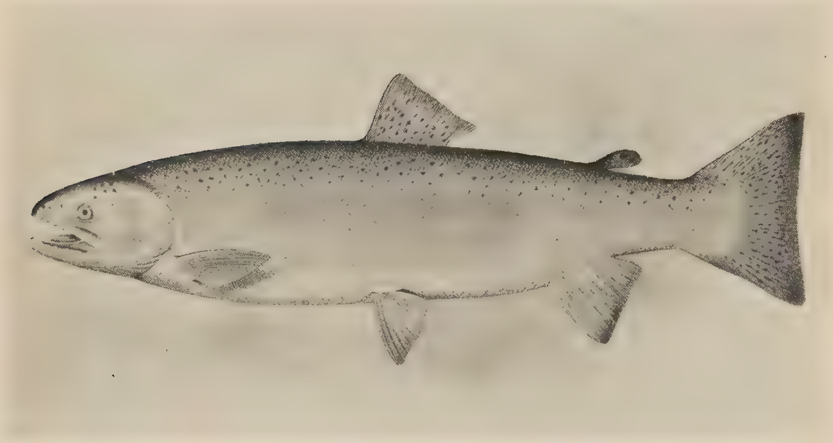
1935. The breeding activities of the little redfish, a landlocked form of the sockeye salmon, *Oncorhynchus nerka*. Mid-Pacific Magazine, pp. 67–77, figs. 1–4.

WHITE, H. C.

1930. Some observations on the eastern brook trout, *S. fontinalis* of Prince Edward Is. Trans. Amer. Fish. Soc., vol. 60, pp. 101–138.

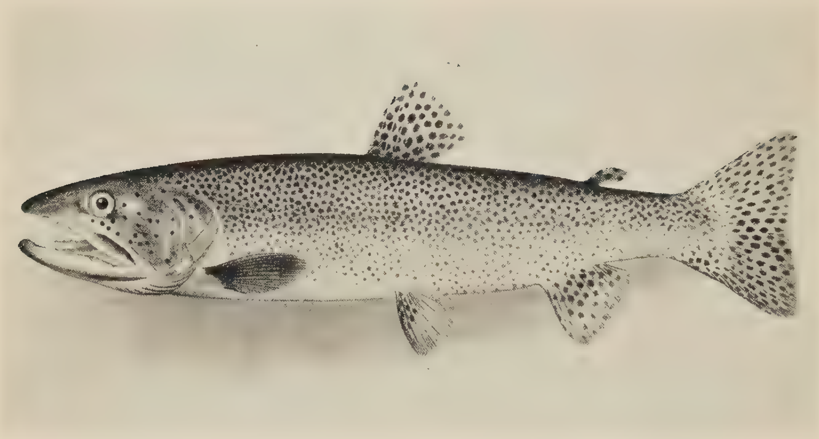


1. *Oncorhynchus nerka*, male red salmon or sockeye salmon. From Bulletin U. S. Bureau of Fisheries, vol. 26.

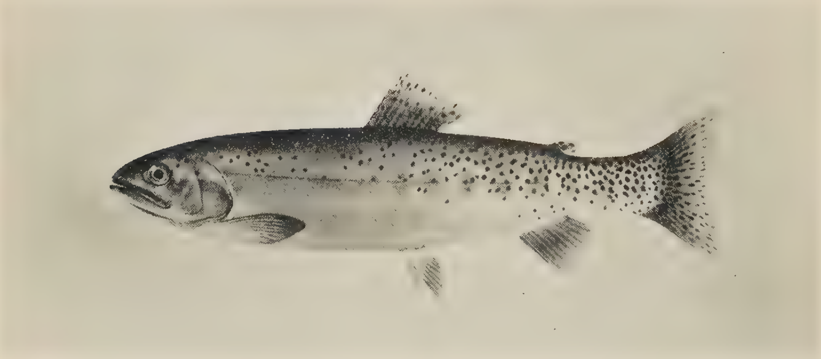


2. *Salmo gairdnerii gairdnerii*, steelhead or rainbow trout. From Bulletin U. S. Bureau of Fisheries, vol. 26.

FISH PORTRAITS.

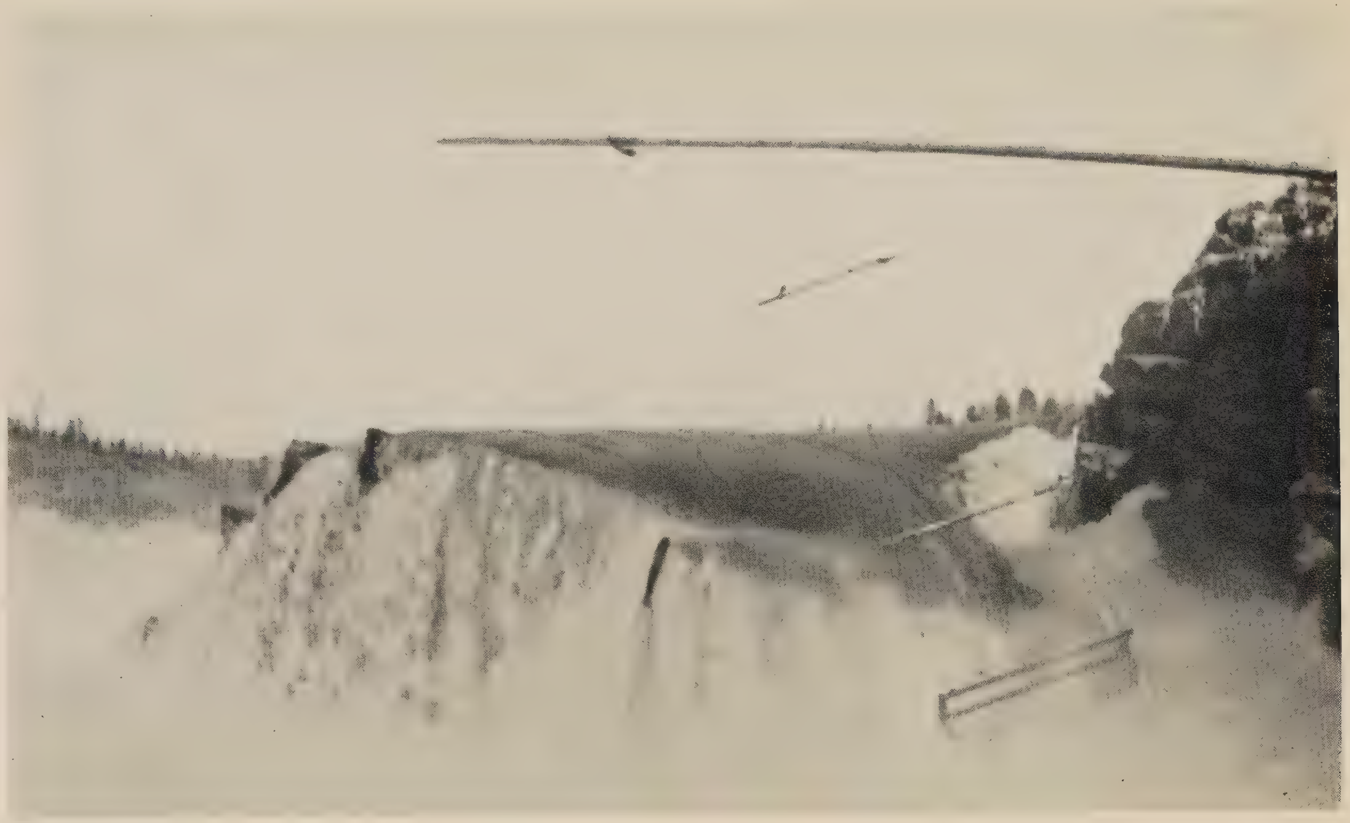


1. *Salmo clarkii clarkii*, large adult of sea run coastal cutthroat trout. From Bulletin U. S. Bureau of Fisheries, vol. 26.



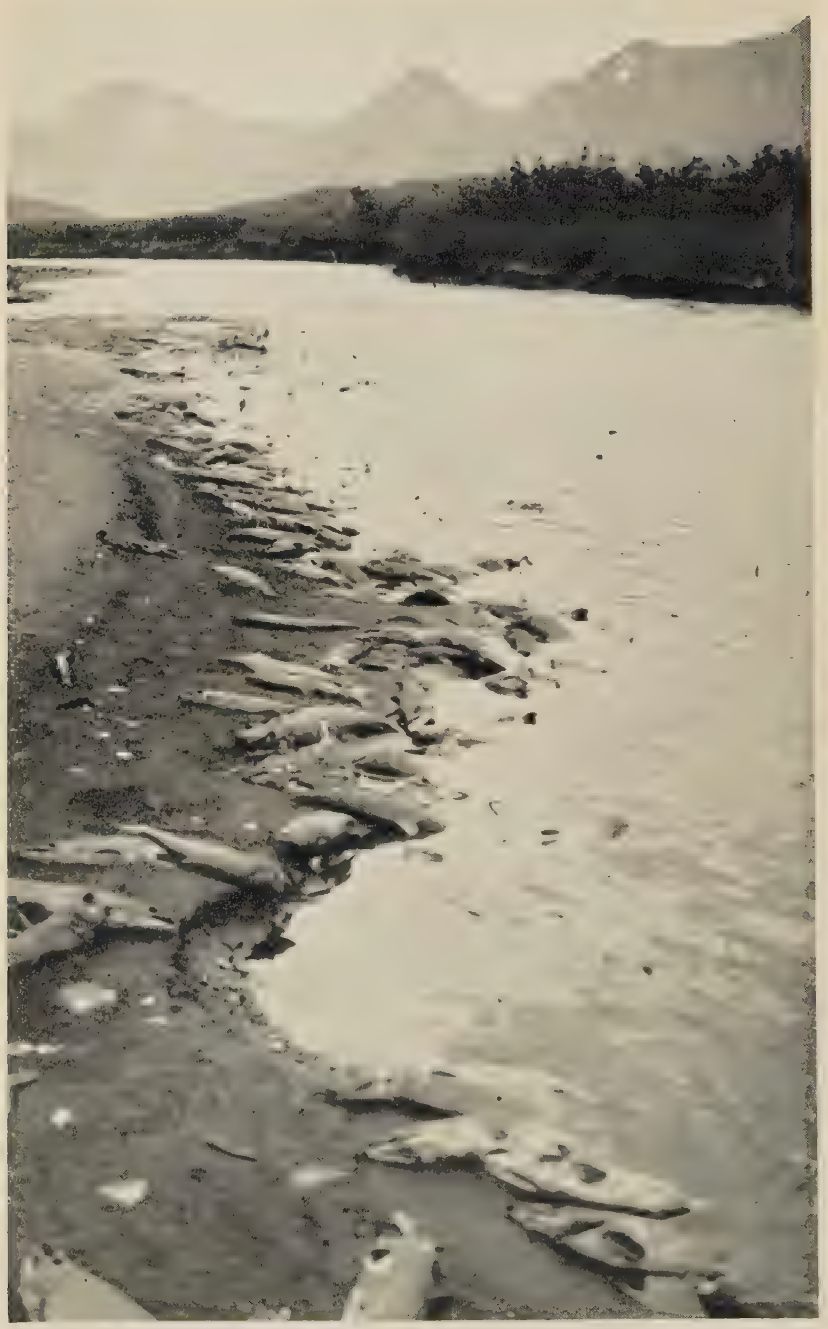
2. *Salmo clarkii lewisi*, Yellowstone black-spotted cutthroat trout. Reproduced by permission of Department of Fisheries, Ottawa, and the Biological Board of Canada from the Trout and Other Game Fishes of British Columbia, by J. R. Dymond.

FISH PORTRAITS.



U. S. Bureau of Fisheries

A PHOTOGRAPH, TAKEN BY A. J. SUOMELA, OF A STEELHEAD (SALMO GAIRDNERII GAIRDNERII) ATTEMPTING TO JUMP OVER THE KETTLE FALLS OF THE COLUMBIA RIVER IN WASHINGTON.



U. S. Bureau of Fisheries

A PHOTOGRAPH OF SALMON THAT HAVE COMPLETED THEIR LIFE CYCLE IN THE ALEE RIVER, CHIGNIK, ALASKA.

These spawned-out fish, which have died, were carried downstream by the current of the river until stranded on gravel, rocks, or sand bars. Their bodies will gradually decompose, furnishing food for aquatic organisms that later may serve as food for the baby salmon.

A PAIR OF STEELHEAD TROUT OVER A NEST IN WADDELL CREEK 40 MILES SOUTH OF SAN FRANCISCO, CALIF., APRIL 1933.

The larger fish is the female. Note two small males ranged about the sides of the nest and below it. This photograph, taken by Dr. Paul R. Needham, was published in the Transactions of the American Fisheries Society, volume [illegible], opposite page [illegible], but was kindly loaned to the author by Dr. Needham.

WHAT IS ENTOMOLOGY?[1]

By Lee A. Strong

Chief, Bureau of Entomology and Plant Quarantine,
U. S. Department of Agriculture

[With 16 plates]

What is entomology? Webster says, "Entomology is the department of zoology that treats of insects; also a treatise on that subject." How does the particular department of zoology referred to treat of insects? Treating of insects takes on many forms. It has many ramifications. It affects many people. It affects the health, the comfort, the well-being, and fortunes of as many individuals in the world as perhaps any other applied science.

In species and kinds insects outnumber most, if not all, groups of living organisms. There are known more than 700,000 kinds of described and named insects in the world. There are 75,000 kinds so reported from North America north of Mexico. Of the 75,000 kinds in North America there are estimated to be 6,500 kinds of insects which are so injurious to agriculture in the United States that records of their occurrence are consistently reported to the Insect Pest Survey. It is obvious, therefore, that while entomology treats of insects, an entomologist can in reason treat only of a comparatively few species of insects. In schools the teachers can teach the students only the principles of the science and general fundamentals of insect structure, classification, physiology, habits, and general distribution, leaving the student to specialize in the group of insects or branch of entomological work desired after graduation in the securing of degrees, in teaching, or in employment.

First, in our work we must know what insects are, and taxonomy is really one of the important points in treating of insects. The study and interpretation of structural characters for the purpose of classification and identification have a most important place in the science of entomology. For example, the species of *Cochliomyia* look much alike, particularly the forms commonly called screwworms. Cushing, while working on this group with Patton in England, found that what had been considered as one form, *C. macellaria*, was really two species readily distinguished by structural differences. Later studies showed that their newly described *americana* is the primary pest, the one which feeds on living tissue. This, although complicating the whole screwworm problem in a certain sense, simplified it in other ways and demonstrated again the value of taxonomic studies. Such studies make it possible to differentiate control measures in the field, to dispose properly of infested shipments moving in commerce, and to apply appropriate quarantine measures.

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[1] Address given at the Second Florida Entomological Conference, Gainesville, Fla., March 19, 1937.

Life-history studies and studies in the laboratory and in the field to find out how the insect lives, how it propagates, how it feeds, how it damages or benefits crops or food or materials, teach us not only about the insect but also what to do about it, a large part of the program of treating of insects. After several years of experiments in the effort to control wireworms, the immature form of the click beetle, physiological studies in connection with the life-history studies developed that the particular poisons being used were not being taken into the system by the insect but were being thrown out before reaching the stomach.

Spraying with lead arsenate has long been a standard form of control of insects that bite and chew. Until the human health hazard involved in the use of lead arsenate was fully realized, it was the accepted standard method of control for codling moth, that almost universal pest of apples and pears. Studies on the life history and habits of the Oriental fruit moth made shortly after its discovery in this country revealed that the larva, although a biting and chewing form somewhat similar to that of the codling moth, has a habit of spitting out the first one or two mouthfuls of food and thus escapes the effects of the poison sprayed on the surface of the fruit or twig; hence in this case lead arsenate is not effective.

As is well known, the fecundity of insects is remarkable. Taking the classic example of the ordinary vinegar fly as computed by Maxwell-Lefroy—if the offspring of a single pair lived for 1 year and none of the young died and none of the bodies decomposed, the total mass of ponderable material produced would bury the entire earth a million miles deep. Of course, there is nothing to worry about in this direction, because it never would happen. In the first place, comparatively speaking, almost all the offspring die and those that die do decay, so there is no ponderable mass of sufficient size left to bury any part of the earth. Despite the fact that such a large proportion of the offspring of insects do die, however, there is a tremendous increase in the population of destructive insects from year to year. Notwithstanding these tremendous populations of insect pests from time to time which take a huge toll in crops and which spread disease and annoy human kind in other ways, there is no such thing as the insects of the world wiping out civilization. However, if crops and foods are to be produced in sufficient quantity for our needs and at a cost making it profitable to so produce, insects must be controlled. Control depends upon research; research means to study, get the facts.

The science of entomology is fighting insects on many fronts, and every possible known advantage is being taken even to the use of insects against insects. The first importation of insect parasites into the United States was that of a wasp from England in 1883 to aid in the control of the cabbage worm. Since that date 403 species of insect parasites and predators have been imported from Europe, Africa, Australia, Japan, and other countries, and 73 of these have become established. When Koebele introduced the *Vedalia* into California and it cleaned up the cottony cushion scale, an insect which threatened the very existence of the citrus industry in that State, there was furnished an early and graphic example of the value of the use of beneficial insects. A beetle which feeds upon mealybugs was imported into the United States from Australia in 1891, and since that date has been distributed to 33 other countries. A parasitic wasp which is native to North America and which attacks the woolly apple aphid and brings it under control has been sent from the United States to 40 countries throughout the world since the first shipment to France in 1920. When, at the suggestion of the officials of the Florida State Plant Board, Clausen was sent to Malaya to take parasites of the citrus blackfly to Cuba, the results were far-reaching and important. Not only did this action reduce the citrus blackfly in Cuba from a pest of first importance to one of minor rank, but it also reduced the risk which had been present in marked degree of introduction of the pest into this country. Moreover, it was a demonstration of far-sighted planning and of good neighborliness. The work now going on in the collection of beneficial insects, their exchange between nations, and their colonization and study certainly enter into the program of treating of insects.

It will thus be seen that along with the effort to destroy injurious forms of insects, opportunities have not been entirely overlooked to make more helpful to the human race beneficial insects; and among these, of course, one of the outstanding examples is the honeybee. Entomologists have determined that bees are more effective in gathering honey and pollinating plants if they can reach farther with their tongues into deeper flowers for the nectar. Hence an effort has been made with substantial progress in developing bees with longer tongues. Since bees in nature mate on the wing only, this recourse to the practice of eugenics in the bee family has been fraught with difficulty but has been successfully accomplished.

Notwithstanding these efforts we are told from time to time, even by outstanding entomologists, that in our zeal to control or kill injurious insect forms we have too little regard for the well-being of the beneficial forms upon which we depend for pollination of plants and other useful functions. We are frequently told of the killing of colonies of bees through the use of sprays for the control of fruit and crop pests, and we are consequently urged to have more regard for the life of the useful insects even though the injurious forms may in some instances do more harm. These warnings and admonitions are, of course, well meant and should be given every possible consideration. There are as usual two sides to these arguments. A recent article in one of the leading bee publications referred to the warning given by entomologists of the possible grasshopper outbreak the coming season and indicated that grasshoppers were very abundant in most of the sweetclover regions the past season. It was pointed out that the sweetclover is one of the favorite honey plants for the honeybee and that the invasion of grasshoppers might well prove serious to the beekeeper since sweetclover is attractive to the grasshoppers as a food and is the sole source of surplus honey in a large area. Of course, the obvious answer is to heed this particular warning and poison the grasshoppers to save the food for the bees, and since grasshoppers can be poisoned with a material which is not attractive to the bees, there can be no argument as to what should be done.

It is necessary to treat of insects when controlling and eradicating many of the plant diseases. The Dutch elm disease, introduced from abroad and now constituting a serious threat to the elms of this country, is spread by at least two insects and possibly by more. Sugarcane mosaic is carried by insects. The most important disease of sugar beets, curly top, is spread by leafhoppers. It is suspected that phony disease of the peach may be spread by insects, although definite information on this point is lacking. It has recently been found that peach yellows is spread by an insect vector, and no doubt insects enter into the general program of plant-disease spread and control more than we know. Insects themselves are affected by diseases, and attempts are being made to develop and culture the diseases with a view to using them in the fight against injurious insects.

Treating of insects through studies of plant resistance has its place in the picture. Man is limited in his consumption of many members of the plant kingdom because of their bad taste, poor quality as food, fibrous composition, poisonous character, or possibly even because they present an unattractive appearance. Investigations by entomologists have revealed that insects such as the hessian fly also have food preferences and limitations in selection of varieties of wheat or even the individual wheat plants for food. Some plants are entirely unsuited for the support of the flies, even when the variety is generally suitable, and parent flies selecting such plants for egg laying doom their offspring to an early death. Other plants may be quite unattractive for egg laying and thus escape infestation. Study of these food and egg-laying peculiarities of the Hessian fly and of other species of insects has indicated the possibility of developing resistant strains of plants entirely suitable for human or livestock consumption but immune or partially immune to insect attack.

In the chemistry of developing insecticides and fungicides it is essential to treat of insects. Knowledge of the insect habits, the methods of fighting, and the character of injury is an essential part of the chemist's approach to the problem of developing a killer. Fungicides must be compatible with insecticides, and vice versa; hence plant diseases must be taken into account. No more attentive listeners will be found at entomological meetings than the chemists of the Division of Insecticide Investigations in the Bureau of Entomology and Plant Quarantine.

In studying and fighting insects it must be remembered that many of the most injurious forms spend a large portion of their lifetime in the ground as larvae or worms. The Japanese beetle, for example, a serious pest on the Atlantic seaboard, spends 9 months of the year in the soil as a larva. Many of the wireworms are in the soil 3 years in the worm stage and, as is well known, the periodical cicada spends 17 years in the soil. Entomologists are thus dealing with species which are not able to give expression to the reaction of the various insecticides and other control measures used, and observations are difficult and necessarily infrequent. So when entomologists are asked why after many years of study on a certain insect they are not able to immediately outline adequate control measures, there is a real answer. And at that the progress made probably does not suffer in comparison with the progress made by other branches of science in the study, for example, of many human ailments, even that most ordinary thing, the common cold.

Conservation of natural resources involves treating of insects; and to a far greater degree than is now practiced if it is to be real conservation. You may find thousands of square miles of forested areas in this country where the best of the timber has been killed by insects. In large areas in the high forests of the West the losses occasioned by insects exceed the combined value of timber cut for lumber and burned by fire. Does this suggest treating of insects? Our range lands are denuded over large areas by the feeding of grasshoppers and Mormon crickets. Not only do we lose the range but an erosion problem is created. Does not real conservation suggest something here? What about the conservation of animals? Consider the fever tick, the buffalo gnat, the screwworm, the insects that prey on wildlife. How about the health of humans? What of yellow fever, malaria, spotted fever, tularemia, all transmitted by insects; and consider for just a moment merely the comfort of humans; is it not affected by the housefly, the mosquito, the sandfly, or the eye gnat, as well as other forms not usually mentioned above a whisper? Think of the furs, the clothing destroyed by clothes moths, the furniture destroyed by carpet beetles, and the furniture and buildings wrecked by termites. Does not all this suggest some of the reasons for the treating of insects?

Treating of insects includes also consideration of their distribution and spread. Man, by his means of communication and desire for products, plants, and materials found in other sections, has provided many ways to spread insects into new areas. Examples of this are numerous; that there are not more of them is surprising. But the entomologist has not overlooked the importance of this and the serious consequences that may arise if no restrictions are imposed. It has been the entomologist who was, and still is, the prime mover in the establishment and enforcement of laws and regulations to prevent the spread of plant pests. This has led to the development of another specialized field in this science of treating insects, a field touching many activities, at home and abroad; activities which affect the commerce of the country and the world, requiring the examination of ships entering our ports, inspection and treatment of products, fumigation of railway cars; and many others too numerous to mention. Specialization in this phase of the work of treating of insects, one of the newer aspects of the science, has come into importance so recently that its principles and fundamentals receive only inadequate consideration in the preparatory instructions offered by many schools of higher learning. This, despite the fact that the work of quarantine is carried on by Federal and State forces in as close cooperation as any work in the treating of insects that can be mentioned.

What facilities are available for treating of insects? In the Bureau of Entomology and Plant Quarantine research work on insects is going on outside of Washington and outside of the National Agricultural Research Center at Beltsville, Md., at 92 stations in 34 States, and at any one station several divisions of the Bureau may be located, as for example, Orlando, Fla. Research work including parasite studies is also going on at stations in Hawaii, Puerto Rico, the Canal Zone, France, and Japan. Quarantine and control work is being carried on at 166 permanent stations in 41 States and in Hawaii and Puerto Rico. These are manned by permanent employees and do not take into account the large number of seasonal or temporary employees used in various features of the work.

When entomological work in the United States Department of Agriculture attained the status of a bureau July 1, 1904, the appropriation was $82,450. This fiscal year it is $5,317,675, with 1,621 permanent employees. In addition there have been made available during the past year $12,000,000 in emergency funds, and last summer the peak employment figure was 27,000 people on pest-control projects paid with emergency funds exclusive of regular appropriations.

Industrial and commercial concerns have also entered the field of treating of insects, studying and developing facts as well as producing materials used for control and applying treatments developed. This commercial and industrial aspect is additional recognition of the science of entomology. The science that treats of insects must not overlook its importance, for in its application industry has an essential part. What is the practical importance of knowing the toxic effect of a chemical on the insect unless industry can make it available for use?

Entomological work has grown rapidly in colleges and universities. State experiment stations are accomplishing things of great importance to agriculture and to humanity. The State of Florida, for example, has profited more than is realized from such work. The eradication of citrus canker in this State saved the citrus industry. It was accomplished by men trained in entomological and eradication work. The eradication of the Mediterranean fruit fly was accomplished only because men trained in entomological work and in eradication practices were in Florida and available; not only available but unafraid and with that vision which is necessary to great accomplishments. In these two programs alone major catastrophes were averted.

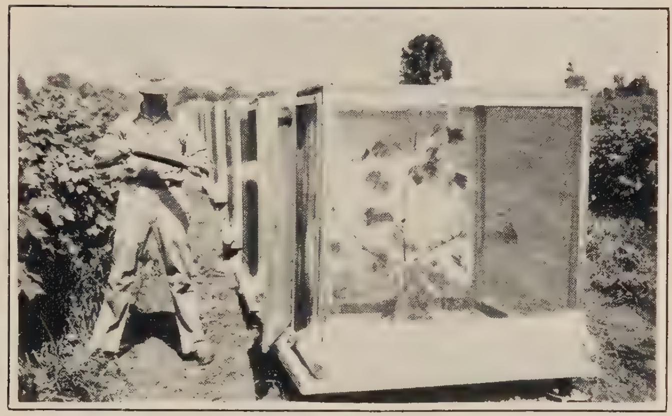
So, finally, what is entomology? That branch of zoology that treats of insects, as Mr. Webster said? Undoubtedly, and much more. It is a science that contributes materially and without ostentation to the health, comfort, welfare, and happiness of the human race and of a large part of the animal kingdom.

ENTOMOLOGICAL LABORATORY
BELTSVILLE, MARYLAND.

TAXONOMIST IDENTIFYING INSECTS.

STUDYING THE EFFECT OF POISON ON THE HEART OF AN INSECT.

FIELD HEADQUARTERS.



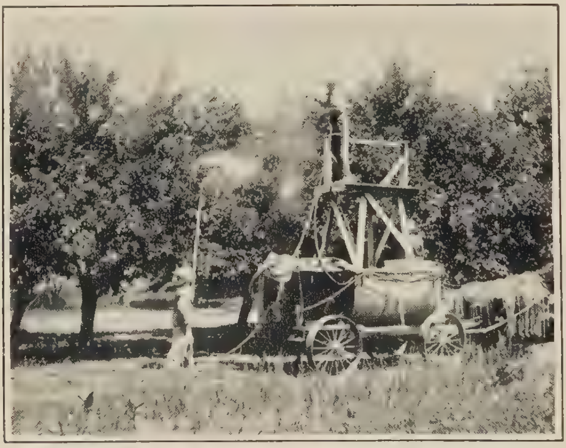
DUSTING PLANTS IN FIELD CAGES.

EXAMINING MATERIAL TO DETERMINE THE RESULTS OF AN EXPERIMENT.

INVESTIGATIONS TO DEVELOP CONTROL METHODS.

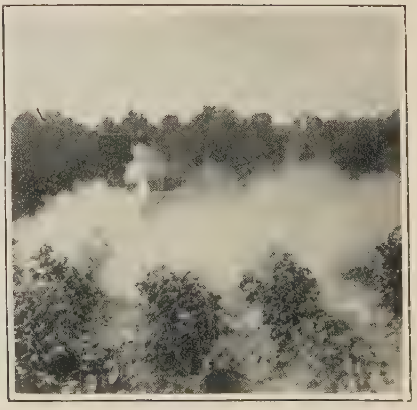
HAND SPRAYING IN THE HOME GARDEN.

MUNICIPAL POWER OUTFIT SPRAYING SHADE TREES.



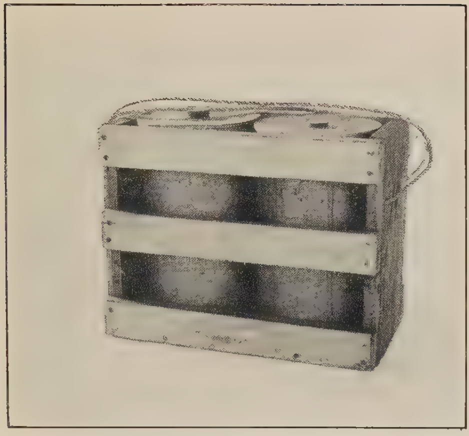
POWER SPRAYING OF A COMMERCIAL ORCHARD.

KNAPSACK DUSTING OF TRUCK CROPS.

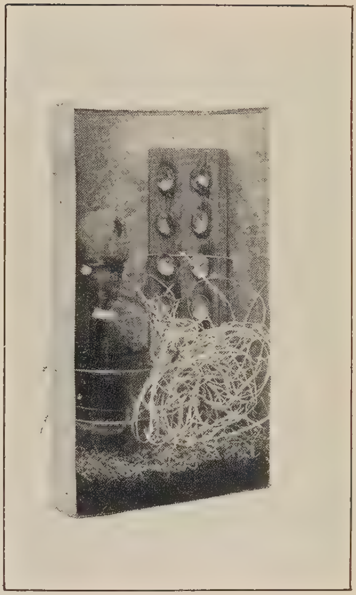


POWER DUSTER IN USE ON COTTON.

METHODS OF SPRAYING AND DUSTING.



CRATED PARASITE CAGES.

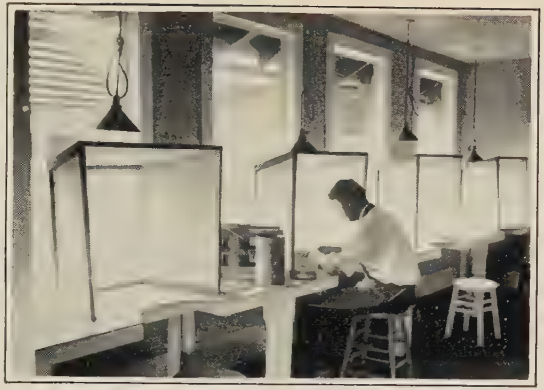


SECTION OF A PARASITE CAGE.

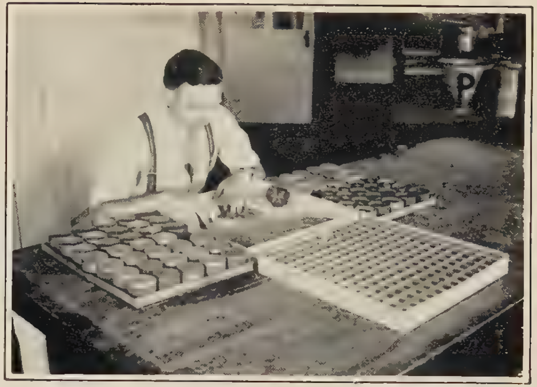
SHIPMENT OF PARASITES EN ROUTE TO STEAMER IN JAPAN AND THENCE TO THE UNITED STATES.

SHIPMENT OF PARASITES ON DECK OF STEAMER FROM MALAYA TO UNITED STATES.

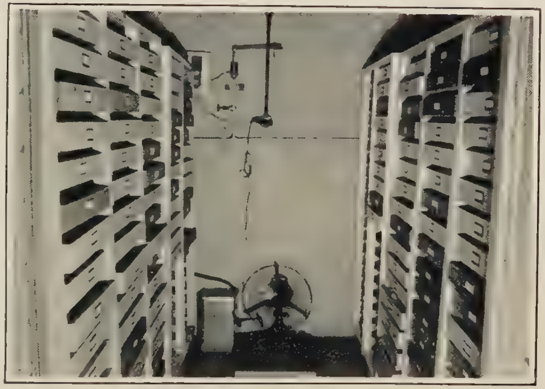
THE IMPORTATION OF PARASITES.



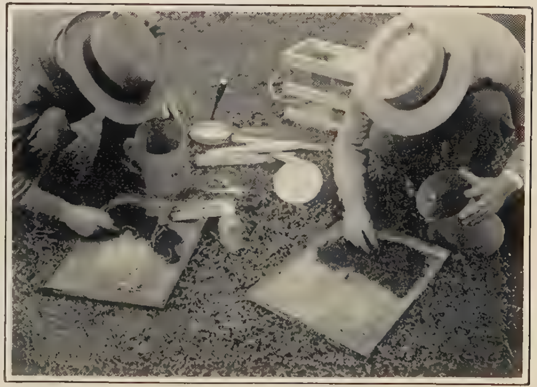
SORTING PARASITES FROM ABROAD.



EQUIPMENT USED IN REARING TIPHIA PARASITES.



PARASITES IN COLD STORAGE.



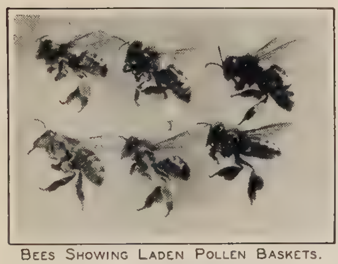
LIBERATING JAPANESE BEETLE PARASITES IN THE FIELD.

REARING PARASITES.

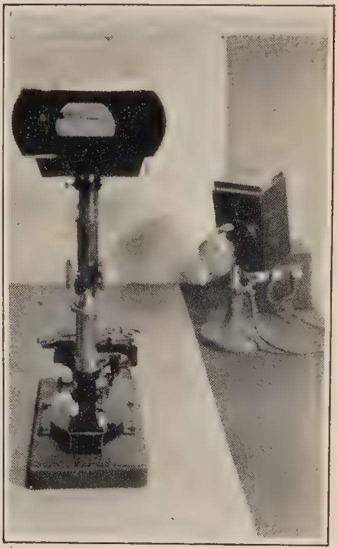
A HONEYBEE GATHERING POLLEN.

BEE HIVES PLACED IN ORCHARD TO IMPROVE SET OF FRUIT.

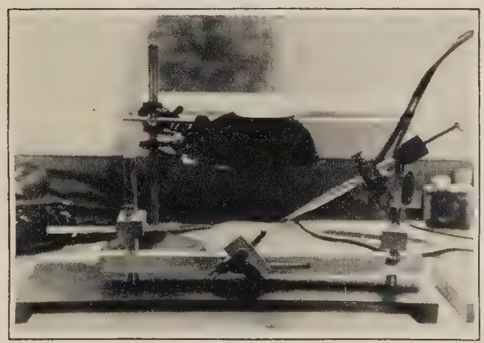
BEE KEEPING



BEES SHOWING LADEN POLLEN BASKETS.



INSTRUMENT FOR MEASURING LENGTH OF BEE'S TONGUE.

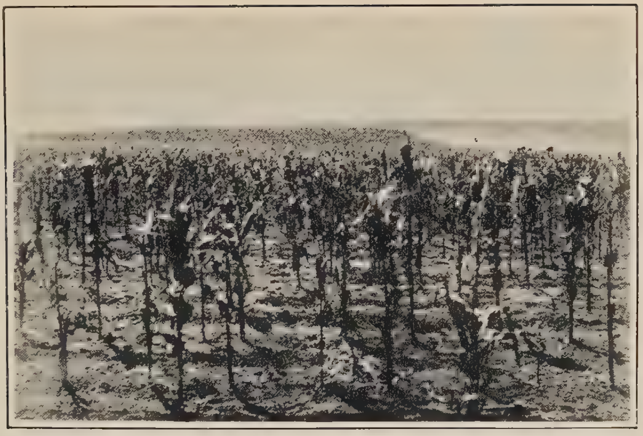


APPARATUS FOR ARTIFICIAL INSEMINATION OF QUEEN BEES.

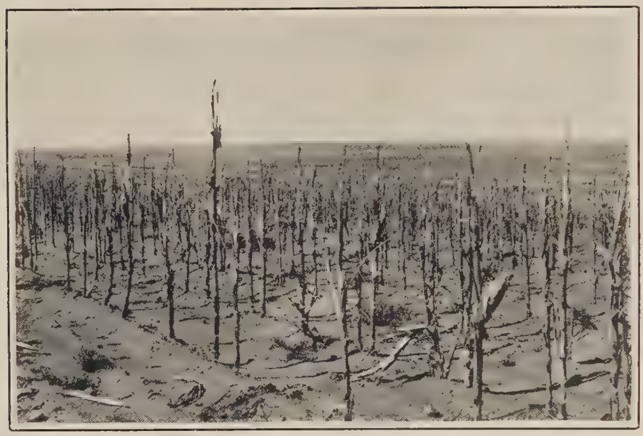
DUSTING A SWAMP TO CONTROL MOSQUITOES.

DUSTING COTTON TO CONTROL BOLL WEEVIL.

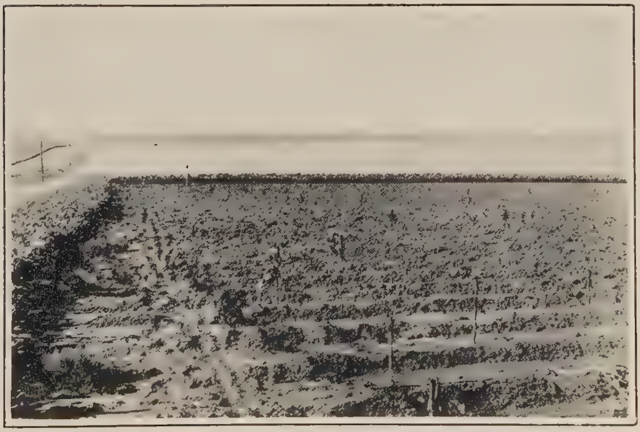
Use of Airplane in Entomology.



AT TIME OF ATTACK.



A FEW DAYS LATER.



STILL LATER.

GRASSHOPPER DAMAGE TO A CORNFIELD.

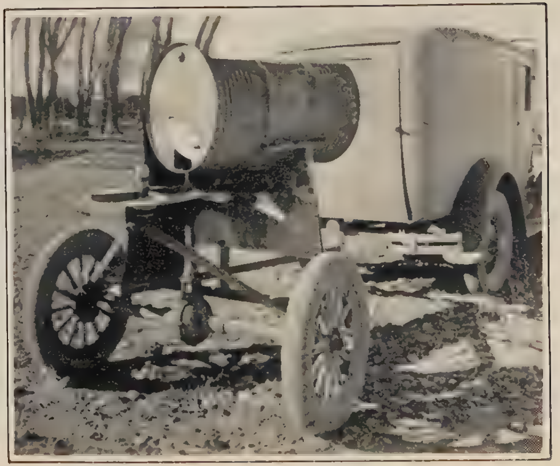
GRASS COMPLETELY DEVOURED

A SMALL PATCH OF RANGE PROTECTED FROM GRASSHOPPERS

GRASSHOPPER DAMAGE TO RANGE.

HAND DISTRIBUTION OF BAIT ON FOOT AND FROM A TRUCK.

MIXING BAIT BY HAND.



A MECHANICAL BAIT DISTRIBUTOR.

GRASSHOPPER BAIT.

CORN LEAF APHID
CARRIER OF
SUGARCANE MOSAIC.

EUROPEAN BARK BEETLE
CARRIER OF
DUTCH ELM DISEASE.

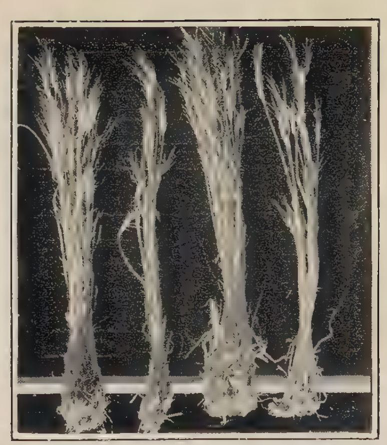
THREE SPOTTED LEAFHOPPER
CARRIER OF
PEACH YELLOWS.

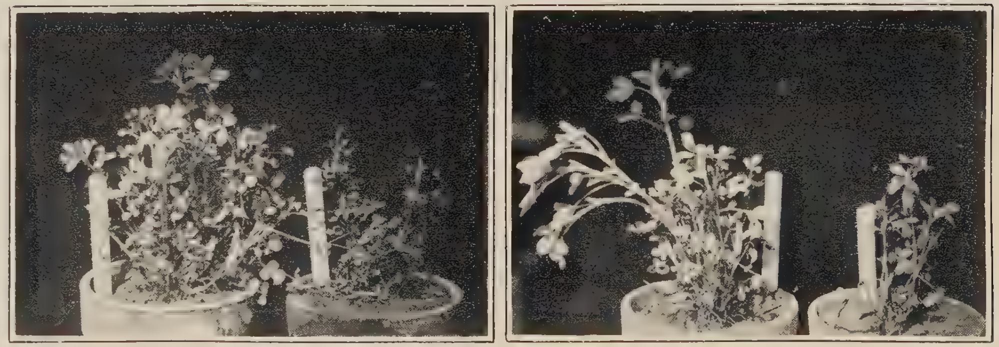
BEET LEAFHOPPER
CARRIER OF
SUGARBEET CURLY TOP.

INSECT CARRIERS OF PLANT DISEASES.

LEFT: ROW OF HESSIAN FLY RESISTANT WHEAT BETWEEN TWO ROWS OF SUSCEPTIBLE WHEAT.

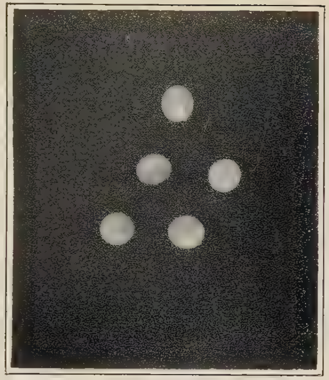
RIGHT: RESISTANT AND NONRESISTANT WHEAT. YIELD FROM NURSERY ROWS.



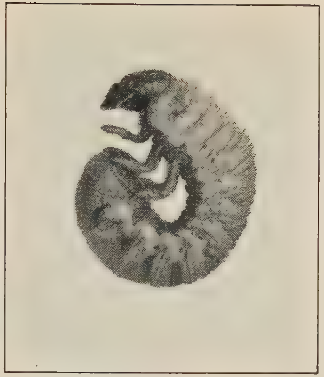


PEA APHID RESISTANT AND SUSCEPTIBLE VARIETIES OF ALFALFA PLANTS IN LEFT POT IN EACH PICTURE ARE RESISTANT.

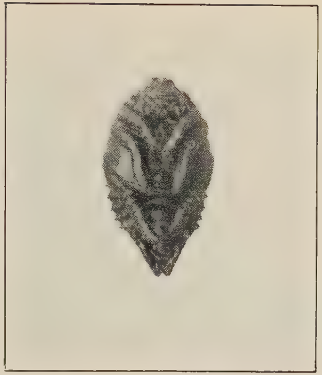
INSECT-RESISTANT PLANTS.



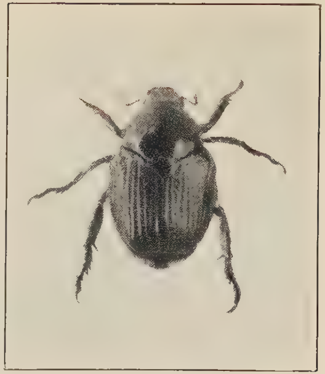
EGGS
LATE JULY



LARVA
EARLY AUGUST TO EARLY MAY



PUPA
LATE MAY AND EARLY JUNE



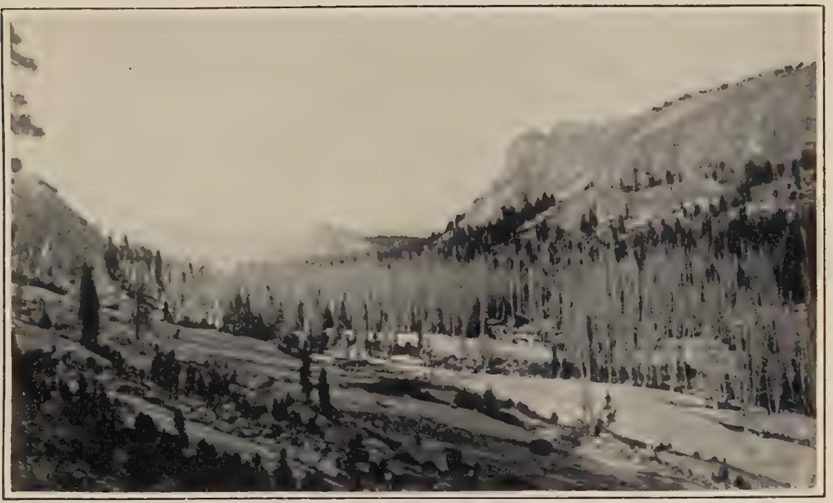
ADULT
MID JUNE TO EARLY SEPTEMBER

PEACH TREE DEFOLIATED

CABBAGE PLANT ATTACKED

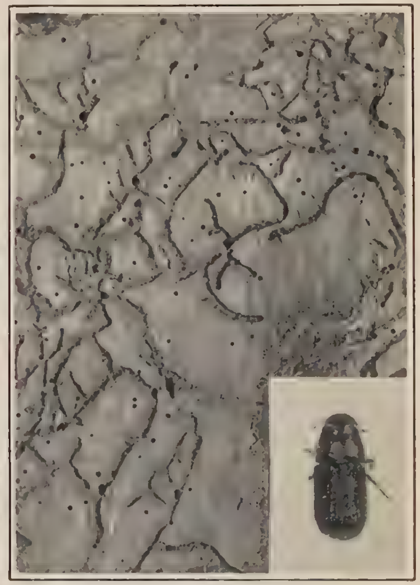
SOD INJURY

THE JAPANESE BEETLE.



FOREST KILLED BY BARK BEETLES.

TREES KILLED BY BARK BEETLES.



BARK OF TREE REMOVED TO SHOW BARK-BEETLE GALLERIES. INSET: A BARK BEETLE.

FOREST INSECTS.

INSPECTION TO EXCLUDE PLANT PESTS.

MAIZE—OUR HERITAGE FROM THE INDIAN

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[With 30 plates]

INTRODUCTION

All of our cultivated crops were domesticated in prehistoric times, some of them in the Old, others in the New World. When the Europeans discovered the New World, they found a highly developed agriculture extending over most of the two Americas and the outlying islands. This agriculture was based on plants unknown in the Old World, and the cultural system followed made no use of beasts of draught and burden. Aboriginal American agriculture was wholly manual, and the crops raised were consumed directly by the producers. The only domesticated animals of the prediscovery Americans were the dog, the turkey, and the llama.

The key crop of the New World agriculture and the chief basis of Indian economy was the noble grass we know as corn, as Indian corn, or as our derivative of its Arawak name—maize. Although the European races have largely displaced the Indian population of the Americas, corn has retained its place as the principal crop of the New World. It is grown in every State of the United States and is by far the most valuable single crop produced in the Western Hemisphere. It is the only domesticated plant that can be grown over the entire range of climate, soils, and day lengths found in the territory extending from the Canadian border through the Central American tropics to southern Chile, and from sea level to an altitude of 12,000 feet.

No other cereal is as useful to man in so many ways. Not only are the seeds borne in handy packages of from 500 to 1,000, but they are edible and nutritious long before maturity. The ears of corn lend themselves well to storage, and the seeds, being naked, require no threshing or winnowing. The crop produces more food value per unit of area than any other grain, though of course less per man-hour than the Old World cereals such as wheat, which require no care after planting. The American agricultural system, based on hand labor and involving either irrigation or the clearing of forests every few years, required a cereal giving maximum returns for the land used. And in maize the American Indian developed a food plant capable of supporting a family of five for an entire year on the production from 4 acres.

Not only are the seeds of corn edible scarcely 3 weeks after fertilization, but other parts of this plant were eaten. The Indians made a palatable soup from the corn pollen which is produced in such great abundance, and they also prepared a food from the tassels. Even the fungus parasite—the common smut—furnishes a food highly appreciated by certain Indian tribes of Mexico, much as the Chinese value the smutted shoots of wild rice. Maize, however, supplied more than mere food to the Indian. It was an important part of his religious life, and quite early the element of art entered his breeding of this grass, for in no other way can we account for the highly decorative features of this majestic plant. The seeds run almost the entire gamut of colors, and red, blue, black, brown, pink, yellow, striped, banded, and spotted are common among the corns of the Indians. The various combinations of colors and patterns and of seeds upon the ear afford an almost endless variety of arrangement.

Although we have settled largely on yellow and white seeds in our commercial varieties, the rejected colors are still appreciated for their ornamental qualities, and the Indians retain a preference for the blue seeds in the preparation of their corn cakes or tortillas.

In addition to seed colors there is a great variety of seed shapes and sizes, ranging from the diminutive pointed popcorn seeds, some smaller than a kernel of wheat, to the giant disk-shaped seeds of the Cuzco corn. These latter are so large, often approximating the diameter of a quarter, that after being boiled they are eaten singly like grapes, the endosperm being squeezed out of the outer skin or pericarp, which is then discarded (pl. 1).

Aside from the seeds there is a great range of plant colors. In our commercial fields of corn we are accustomed only to green plants but there are various kinds of red, purple, and variegated corn plants, some of which at one time were listed in the flower catalogs and were used as ornamentals in the circular flower beds common during the cast-iron deer era.

Corn was an object of veneration to the Indians and figured in their art no less than in their diet. The plant was skillfully formalized for pottery decoration without sacrificing its distinctive characteristics (fig. 1). This feeling for the decorative possibilities of the corn plant was shared by the peoples of the Old World. In far Nippon where the arts are close to the land, the immigrant corn plant was used as early as the seventeenth century to achieve a strikingly beautiful effect as is shown by the handsome screen now in the Freer Gallery of Art.

In our country before our agricultural antecedents were swamped by the industrial era, the corn plant had begun to find its place in the decorative arts. Benjamin Latrobe, who had so much to do with the building of the Nation's Capitol, made use of ears of corn in a design for column capitals used in that structure at the entrance to the old Supreme Court library (pl. 2). These capitals are the oldest known replicas of maize wrought by Europeans. They have stood in their present location since their installation, having survived the burning of the Capitol by the British. Most of the other adornments of the Capitol have been shifted around, altered, or rebuilt, but these corn columns, like the living plant in our civilization, have remained permanent. Our southern planters, too, carried their devotion to agriculture with them when they built their town residences, and several styles of attractive iron corn fences still enclose some of the gardens in New Orleans (pl. 3).

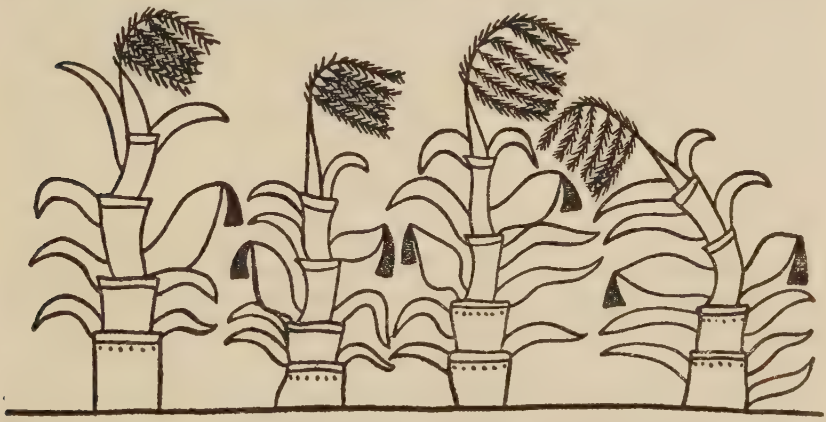


FIGURE 1.—Formalized corn plants in ancient pottery decoration: a design on a clay vessel from the Valle de Chicama, Peru. (Copy by Lehmann.)

At the present time with the shift of our population from the farms to the cities, the close connection between corn and our prosperity is not appreciated. Indeed, many persons have only a vague idea of just what a corn plant looks like (pl. 4). Yet we are today very much of a corn civilization, with an annual per capita consumption of approximately 16 bushels. The agricultural Indians subsisting principally on corn—so much so that in some places this grain comprises 85 percent of the diet—do not consume more. It is true, corn does not enter directly so completely into our diet as it does that of the Central American Indians, but it is an important part of our economy.

Aside from its materialistic value, maize has also become important to our intellectual development, for this plant has proved to be almost uniquely fitted for determining the facts of heredity. Students of genetics, the science of heredity, have described and analyzed several hundred mutations in maize and in so doing have advanced our knowledge of how traits are transmitted from one generation to another. By means of the maize plant they have solved many of the problems of the cell mechanics involved in reproduction.

Despite its importance in ancient and in modern times, nothing certain is known as to the origin of corn. What little knowledge we possess of this subject results from studies in the diverse sciences of morphology, genetics, and cytology. The attempts thus far made to reconstruct the probable past of this perplexing cereal, to the satisfaction of all students of the problem, have not met with success. To a large extent the difficulty of drawing a faultless picture of the origin of maize results from the contradictory evidence supplied by the plant itself. This can mean only that some of the essential pieces of our puzzle are missing or perhaps are being overlooked. In any event the lack of accord among corn experts is an indication of a sustained and healthy interest which should lead eventually to a happy ending.

HISTORY

In comparison with its antiquity as a domesticated plant the recorded history of corn is brief, being limited, of course, to the years following the discovery of America. The first definite date in the history of maize is November 5, 1492, when two Spaniards, dispatched to the interior of Cuba on October 28 by Columbus, returned to report that the ground was sown with "a sort of grain they call maize, which was well tasted, bak'd, dry'd, and made into flour." No record has been found of maize having reached the Old World previous to the voyages of the Spaniards, and the botanical evidence is conclusive that maize originated in the Western Hemisphere. After the voyages of Columbus maize spread rapidly throughout the Old World, reaching China probably early in the sixteenth century.

Corn, of course, is referred to in early colonial documents, all the accounts showing it to be a completely domesticated plant nurtured by the Indians. The Indians, whose welfare depended upon this plant, attributed its origin to the gods, and some of these legends orally preserved through the centuries have been recorded. Many elaborate ceremonies were evolved to insure the welfare of this cereal, but neither the legends nor the ceremonies afford any clues as to how corn came to be the plant it is.

The first written records, then, show that corn 400 years ago was as it is today and the Indian accounts of its origin, though poetic, are but fanciful myths. Fortunately, the archeological record is more extensive and embraces a much longer period of time than the printed accounts. Excavations in Bolivia and in Peru have disclosed ears of corn perhaps 2,000 years old, and in our own country, Basket Maker burials in Utah, roughly a thousand years old, have yielded perfectly preserved ears (pls. 5 and 6). From the mounds of Ohio and the caves of the Ozarks have come charred specimens of grain and cobs that show corn in no wise different from the kinds that must have been grown by the Indians of the same region within historic times. The ears of corn from the Peruvian graves interred about the beginning of our Christian era cannot be distinguished from the ears produced in the same region today. Similarly, the ears of corn buried by the ancient Basket Makers are duplicated today by the ears harvested each fall by our Southwestern Indians.

In addition to the actual ears preserved by interment under the exceptionally favorable conditions in the southwestern United States and western South America, there is the record left by the ancient potters who chose the ear of corn for ceramic decoration. Excellent replicas of ears are found on the pottery of the Aztecs and the Incas (pl. 7). Indeed, so excellent was the replica of one ear that for a number of years it passed among us as a truly fossilized ear of corn. These pottery replicas and exhumed ears all attest that corn as we know it today was a finished product at least 2,000 years ago, so far as its distinctive botanical characteristics are concerned.

Although these prehistoric ears are small according to our standards and give the impression that the corn of the American Indians was diminutive, as a matter of fact the longest ears known were produced by Indians. Indeed the longest ear, one measuring 18 inches from the basal to the apical seeds, was produced by a Navajo Indian (pl. 8). Ears 16 inches in length are not infrequent among the corn of the Indians of Guatemala and Mexico. Eighteen inches, however, is about the limit in length, as the pollen tubes which must reach the ovary for fertilization cannot travel much farther than the 2 feet necessary to reach the lowest seed on an ear of this length.

The corn of the primitives is not primitive corn, and although none of these ears of exceptional size has been preserved in ancient burials there is little reason for doubting that such ears were produced long before the Discovery. Certainly they are grown now by a people little influenced by European culture. Indeed, the cornfields of the Tarahumare Indians of Mexico—cave dwellers and bow-and-arrow people—would be a credit to many of our farmers.

The charred cobs retrieved from Indian mounds and kitchen middens are indeed small, and it is easily understood why they suggest a primitive form of maize. From their size it is unreasonable to believe they bore kernels as large as those of our commercial varieties, and kernels commensurate with the size of the charred cobs would be no larger than grains of wheat. However, when cobs of our commercial varieties are burned they shrink in size until they are indistinguishable from the excavated ancient remains except that the prehistoric cobs have become flattened by the pressure of the overlying soil during their centuries of burial (pl. 9, fig. 1). Not only do we not hold the record for the largest ears, but all the other records are held by the Indians. The smallest ears are produced by the Indians of Peru as are also the largest and the smallest seeds (pl. 9, fig. 2, and pl. 10). So too with the plant itself; the tallest corn plants known are grown by Indians in Mexico and Central America, where stalks 18 feet in height are not uncommon with the ears borne far above the reach of the grower (pl. 11, fig. 1). The archeological record and the present-day culture of the primitives then shows corn fully developed but affords no evidence as to how it might have originated.

In none of the Indian burials nor among living plants has anything been found suggesting a primitive pre-corn. No plant or plant remains that could be classed as directly involved in the ancestry of maize has been discovered. Maize as we know it today extends backward in time to the earliest graves with no stages intermediate between our corn and some less highly domesticated plant.

This highly domesticated cereal furnished the foundation of the three remarkable Indian civilizations—Maya, Inca, and Aztec—yet even today it cannot be said with certainty where, how, or when corn originated. Definite answers to any one of these uncertainties would go far toward solving some of the perplexing questions of the antiquity of man and his civilizations in America, for maize and man are inseparable.

Since the historical and archeological record sheds no light upon the origin of corn, the inquisitive must turn to the botanical and genetic evidence. Like ourselves and our animals, all plants must have had ancestors, and corn is no exception. To reconstruct the origin of corn it is only required that the ancestors be found, but so far has this plant progressed beyond the horde of untamed grasses that experts cannot agree upon its probable parentage nor the manner of its creation.

Corn is never found in the wild nor, indeed, can it survive without the care of man. The very quality that makes it such a useful domesticated plant, the tight adherence of the kernels to a cob wrapped in multiple layers of husks, unfits it for survival as a wild plant. In having this characteristic it lacks the means to distribute its progeny—a fatal failing for an annual plant forced to survive unaided in competition with readily diffusing wild species.

No other cereal has so completely lost the ability to sow the next generation. Indeed, shattering of seed is still a problem among all grains but corn, so that in this respect maize must be classed as the world's most highly domesticated grain.

That corn cannot persist as a wild plant, even under favorable conditions, is accepted by all botanists. Even with competing species eliminated, the hundreds of young seedlings that spring from a buried ear of corn, all within the space of a few inches, struggle with each other for the available water and nutrients to the end that none succeeds in producing seed (pl. 11, fig. 2). Maize, in its present form, therefore—a form it has been seen was attained at least 2,000 years ago—must have survived wholly as the result of man's solicitude. To the American Indian must go the credit for developing corn from its wild ancestors, bringing it to its present high degree of perfection, distributing it over two continents, and maintaining it for several thousand years.

Unlike most domesticated plants of the Old World, whose ancestry is not so beclouded, no one knows what sort of wild plant the American Indian had out of which he fashioned corn. Botanists have placed corn in the tribe of grasses called Tripsaceae, the members of which are differentiated from all other related tribes in having their sexes in separate spikelets. The separation of the sexes is considered to be a fundamental distinction in plant classification, though in the case of the corn tribe it oddly enough produces a strange grouping. On the formal systematic classification, in addition to its American members, the maize tribe includes a group of Asiatic grasses, the best known of which is Job's tears (*Coix lachryma jobi*) (pl. 12, fig.1). To Occidentals the seed-bearing part of Job's tears is familiar as beads, but to the Burmese, who have developed many soft-shelled forms, this plant is an important cereal. The other Asiatic members of the maize tribe have not appealed to man and remain as wholly wild plants under the formidable names of Sclerachne, Polytoca, Chionachne, and Trilobachne.

It should be kept in mind that these Asiatic grasses have been placed in the same tribe with maize largely because of the fact that their sexes are borne in separate spikelets. In appearance they do not suggest maize, and in some respects they occupy a position intermediate between the Tripsaceae and that group of gigantic Old World grasses, the sorghum tribe (pl. 12, fig. 2).

The American relatives of maize fall into two distinct groups or genera, known to botanists as *Tripsacum* and *Euchlaena.* The former is commonly known as gama grass (pl. 13, fig. 1) and the latter is becoming familiar under the Aztec name, teosinte; a name which may be translated as "god grain" (pl. 13, fig. 2, and pl. 14).

The group of gama grasses is widespread in North America and the most ubiquitous member of this group, *Tripsacum dactyloides*, common in the United States, has been found in South America (pl. 15). However, the center of the genus appears to be in Mexico and Guatemala. In those countries this genus is represented by several species and interspecific hybrids, several of which are quite cornlike in general aspect, chiefly because of their large broad leaves and many branched tassellike terminal inflorescences. The commonest member of this genus, *T. dactyloides*, and among the least cornlike, has been hybridized with corn, thus proving a definite relationship, though from the fact that such hybrids are self-sterile it is concluded that the relationship is remote.

The grass known as teosinte has been found only in Mexico and Guatemala. As yet, botanists recognize but two species of teosinte: an annual form designated *Euchlaena mexicana*, and a perennial form called *E. perennis*. This latter species has been found only in a very restricted area in the State of Jalisco, Mexico, whereas the annual species ranges from Southern Chihuahua, Mexico, to the Department of Jutiapa in southern Guatemala (fig. 2).

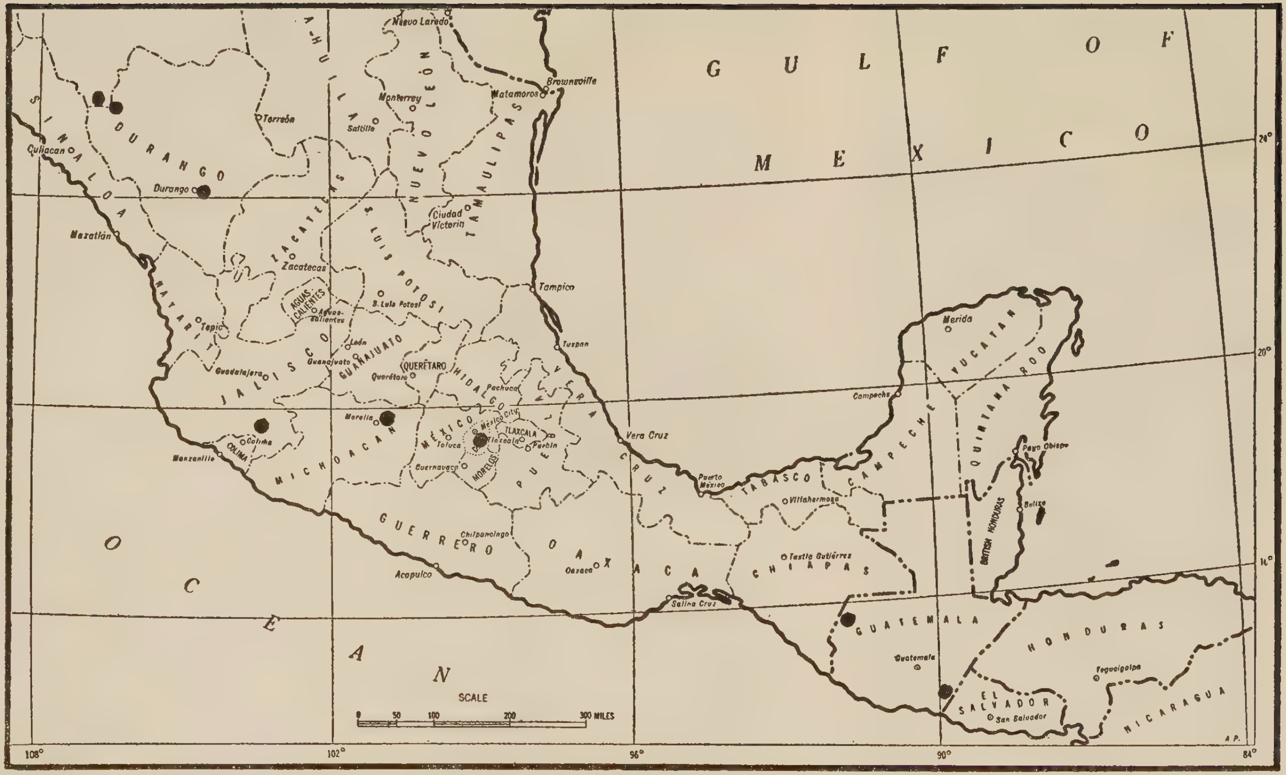
Both species of teosinte hybridize with corn, not only through manual manipulation but also when growing naturally in the field (pl. 16).

Hybrids between corn and the perennial species of teosinte are only partially fertile and are perennial in habit. Morphologically they resemble teosinte much more closely than corn. This failure of the two parents to share equally in the characteristics of their mongrel offspring has been explained by a study of the hereditary mechanism of the two grasses.

The qualities of every individual, be it animal or plant, are determined primarily by the inheritance derived from the parents out of whom it was fashioned. This inheritance, since the rediscovery of Mendel's epochal work on hybrids, is known to be particulate in nature, the parents passing on to their offspring definite particles now named genes. These particles are carried in the cells in strings called chromosomes, and for every species there is a characteristic number of such strings. In corn it has been found that the genes or hereditary particles are carried in 20 strings or chromosomes, and such is the number found in all annual teosinte, but the perennial species of teosinte possesses 40 chromosomes. This double number of chromosomes is presumed to have come about by the failure of a sex cell to divide its chromosomal content or by a doubling following fertilization—a process that would give the resulting plants an extra set of genes. Thus the hybrids between perennial teosinte and corn receive twice as many hereditary particles or genes from the teosinte parent as they do from the corn parent and this disparity accounts for the resemblance such hybrids bear to the grass, teosinte.

The annual form of teosinte hybridizes more freely with maize, and the hybrid offspring are more nearly intermediate in morphological structure between the two grasses. These hybrids are self-fertile, a fact that establishes a very close relationship between the two parental genera.

Natural hybrids between teosinte and corn found in Mexico were mistakenly interpreted once as wild maize, and in more recent times


GULF OF MEXICO
OCEAN
SINALOA
DURANGO
COAHUILA
NUEVO LEÓN
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ZACATECAS
S. LUIS POTOSI
AGUAS CALIENTES
NAYARIT
JALISCO
GUANAJUATO
QUERÉTARO
HIDALGO
VERA CRUZ
MICHOACAN
COLIMA
MÉXICO
TLAXCALA
MORELOS
PUEBLA
GUERRERO
OAXACA
TABASCO
CHIAPAS
CAMPECHE
YUCATAN
QUINTANA ROO
BRITISH HONDURAS
GUATEMALA
HONDURAS
EL SALVADOR
NICARAGUA
Culiacan
Mazatlán
Durango
Torreón
Saltillo
Monterrey
Nuevo Laredo
Matamoros
Brownsville
Ciudad Victoria
Tampico
Tuxpan
Zacatecas
S. Luis Potosí
Aguascalientes
Tepic
Guadalajara
León
Guanajuato
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México City
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Puebla
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Cuernavaca
Morelia
Colima
Manzanillo
Chilpancingo
Acapulco
Oaxaca
Vera Cruz
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FIGURE 2.—Locations where teosinte has been found growing wild. The location shown in the State of Jalisco is of perennial teosinte (*Euchlaena perennis*); all others are for the annual species (*E. mexicana*). Teosinte has been found only in Mexico and Guatemala.

seed of these hybrids was utilized by Luther Burbank in his widely publicized derivation of corn from teosinte in 18 generations. In both Mexico and Guatemala the Indians appreciate that teosinte hybridizes with corn and that the early generations are unsuitable as grain. Observation has taught them, however, that repeatedly backcrossing the hybrids with the maize parent will in a short while eliminate the characteristics contributed by teosinte. It is commonly stated that if the hybrid seed is sown for three generations with corn it will then become a sort of corn with small ears—a fact which may account for the Aztecs having used the designation teosinte.

In several regions of Mexico these hybrids of various generations and of backcrosses are found around and in cornfields in great profusion.

BIRTHPLACE OF MAIZE

As it happens, the place of the origin of maize may be located with more certainty than the manner of its origin. The exact region of origin of any cultivated plant is not known, but botanists have formulated two guiding principles which, when judiciously applied, produce reasonable results. It has been noted that, other things being equal, a species is less variable on the periphery of its distribution than near its center. Presumably, in wandering from the site of origin, only a part of the inherent variation is carried along any one path, so that at any point on the outer circle of distribution only a part of the variation is represented. If the whole circumference of distribution be traversed, probably the entire range of variation possible to the species would be encountered, but this range would be found all in one place only at the center of origin for the species.

Applying this principle to locate the origin of maize would put the beginnings of this cereal in Peru, for in the region of Peru and Bolivia occur the greatest number of maize varieties. As with many broad generalizations, there are exceptions to this one. Other things besides germ plasm in a flux and the random selection of genic complexes influence the variation of a species. Thus the very nature of the Peruvian terrain would explain the multiplication of maize varieties. Cut up into narrow valleys intercommunicating only at the seashore and extending from sea level to great altitudes, even though a single kind of corn started its way up all of the Peruvian valleys, the necessary selection for adaptation to different environments and the lack of ready interchange of seed would result in time in each valley having corn differing from that of the others. The rugged Peruvian terrain would be expected to produce the multiplicity of corn varieties now found there even though a single kind of corn had been introduced.

Although the principle of greatest variation at the center of origin may be discounted, Peru has another claim to the origin of maize in that it had a prehistoric population of exceptionally skilled plant domesticators. All the evidence points to the Incas and pre-Incas as being very able agriculturists, and these people regularly cultivated some 70 species of plants. The archeological evidence also points to the origin of pottery in Peru and its dissemination northward through Central America into Mexico. With clear evidence that Peruvian pots moved into North America, it would seem logical to conclude that their grain might follow the same route.

The real stumbling block to looking upon Peru as the center of origin of maize lies in the unmistakable fact that corn relatives are not now found there. It is difficult to see how corn could have been developed without some plant to begin with, so that proponents of the Peruvian origin of maize are forced to adopt the position that the wild ancestor of maize has been completely eradicated. Until all other hypotheses have been exhausted this sterile conclusion should be held in abeyance, though there is undoubted evidence that much of the original flora of Peru has been profoundly altered by human occupation.

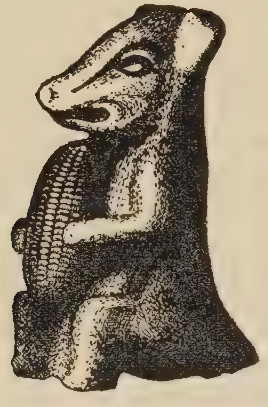


Figure 3.—Pottery whistle made by the Maya Indians of Yucatan showing a replica of a well-developed ear of corn.

All of the known wild relatives of maize are found in Guatemala and Mexico, and these Republics are second only to Peru in the number of maize varieties. At the present time the largest area covered by the closest wild ancestor of maize is in the Department of Huehuetenango, of northwestern Guatemala. This region is now occupied by descendants of that highly civilized group of agricultural Indians, the Maya, and the area is dotted with the masonry ruins of the early Maya peoples. Since this region embraces the maize ancestors, the maize variability, and had a people fully capable of developing maize, it is something better than an idle guess to place the origin of maize within the territory now covered by the Mexican State of Chiapas and the Guatemalan Department of Huehuetenango, with the emphasis on the latter. On this view maize migrated southward as well as northward, the movement southward possibly in exchange for the pots of Peru.

The present-day descendants of the Maya living in the region of teosinte do not use the Aztec name for this plant, but have the Maya name *Salic* or *Salicim*, the latter suggesting an affinity to the Maya word for corn—*ixim*. Farther south in Guatemala the Aztec name of this grass reappears in the Department of Jutiapa, but the Aztecs are known to have controlled this region of Guatemala through a route along the coast extending even into El Salvador as far as Santa Ana.

THEORIES OF ORIGIN

There are several theories current as to how maize may have been derived from its existing American wild relatives. All of these theories have their merits and no one of them offers a definite solution of the mystery. To understand something of the difficulties involved in the transition from the known wild relatives of maize to the cultivated cereal it is essential to understand some of the principal differences between corn and its relatives.

The most familiar part of the corn plant is the ear which botanically constitutes a conundrum and a monstrosity. No other grass possesses such a seed-bearing organ. Naturally, confronted with such a fascinating problem as the origin of the ear of corn, botanists have proposed several theories as to how this structure could have been derived. These theories are not in agreement, and several of them, though plausible, do not take into consideration all of the morphological facts.

All authorities recognize that the ear of corn is a transformed terminal inflorescence of a lateral branch and that its covering of husks came about through a shortening of the internodes. The husks are in reality leaf sheaths that in some varieties, especially of sweet corn, still bear well-developed leaf blades and still retain buds in their axils. Occasionally an ear stalk loses the brachytic features of its internodes and the result is an ear at the end of a vegetative branch (pl. 17, fig. 1). Or at times the buds develop between the ear-bearing nodes and the vegetative branches or suckers, in which case the resulting branches are seen to be intermediate between ears and suckers.

In the wild grass, teosinte, there is a bud in the axil of every leaf except the uppermost, and well-grown plants have a herringbone branch pattern with a branch in the axil of each leaf except the uppermost (pl. 17, fig. 2). These branches are borne in a two-ranked or distichous arrangement. Each branch beginning with the uppermost and descending has one less node than the one next below. In plants not so well grown the internodes of these branches often do not elongate, thus leaving the entire branch structure enclosed in the sheaths much as the husks enclose the ear of maize. In these cases the number of sheaths is that corresponding to the position of the branch on the main axis.

In most types of corn there are no buds in the axils of the leaves above the ear and the ear is borne in the axil of the fifth or sixth leaf from the top, a position that in teosinte would give a branch with seven or eight nodes. If, therefore, the ear of corn has come about through the telescoping or shortening of a branch at this position the ear should be enclosed in seven or eight husks. Actually in most commercial varieties the husk covering is much greater than this. Either several nodes above the ear have been lost or extra nodes have been intercalated on the ear branch.

The terminal panicle of maize, or the tassel, is characterized by having the branching region well defined with branches borne more or less at right angles from the axis, and the panicle terminates in an erect organ known as the central spike. In maize this organ is a continuation of the axis of the panicle or rachis and is covered with paired spikelets arranged in eight or more rows (pl. 19).

In teosinte and in gama grass the rachis does not continue beyond the branching region, and the panicle terminates in a branch in no wise differing from all the other branches (pl. 18). On it, as on all the other branches, the spikelets are in four rows, i. e., two rows of paired spikelets.

The tassel of corn with the central spike removed would be similar to the tassel of teosinte. It was early realized that the ear of corn was the homologue of the central spike of the tassel and there is no disagreement on this score. The ear is envisioned as having arisen through a transformation of male into female spikelets with the suppression of one flower in each spikelet, loss of the lateral branches, and shortening of the internodes. By this means an ear of corn could be derived from the terminal panicle of a lateral branch (pls. 20 and 21).

Although this picture of how the ear could be derived from a corn tassel is satisfactory, it fails to take into account that the organ of the tassel—the central spike—from which the ear is to be derived is as much in need of an explanation as the ear itself. The problem of the origin of the ear thus becomes the problem of the origin of the central spike of the tassel.

The earliest explanation suggested for the origin of the ear was that it came about through a fusion or fasciation of the branches of the panicle. Although the idea of branch coherence was proposed for the ear it would account equally well for the central spike of the maize tassel. This theory is supported by the recurrence of bifurcated and fasciated ears and central spikes but has obtained no histological confirmation (pl. 21).

A second suggestion has been made that the central spike came about through the suppression or reduction of tassel branches into a simple pair of spikelets, thus leaving the central axis surrounded by paired spikelets. This theory derives plausible support from certain peculiar branched forms of maize where the branches extend in an unbroken series of ever-decreasing lengths from the base to the tip of the tassel. In this form of maize, known as ramose, and in certain other similar types, such as branched silkless, all stages between true branches and paired spikelets are found. Where these forms have been hybridized with normal maize there often is, in the generations subsequent to the first, a great variety of intermediate forms showing all degrees of transition from tassel branches to paired spikelets (pl. 22).

Then, too, among the podded forms of maize it is not uncommon for a pair of spikelets to develop into a branch. The process is also seen on both ears and tassels in a variation where the flowers are proliferated.

A third method of deriving the ear has been suggested from a study of the hybrids between corn and teosinte where it has been shown that a yoking of spikelets takes place. In some plants these yokes fit together at right angles, thus constituting an eight-rowed ear (pl. 23), while in others the yokes occur in more complicated figures, giving ears with higher numbers of rows. This theory, while necessitated by the behavior of corn-teosinte hybrids, does not easily account for ears with rows of kernels in multiples of two. This same objection has been raised to the theory of branch coalescence because each branch is a 4-rowed unit and the union of two such branches would give an 8-rowed ear; three would give a 12-rowed ear, etc. The objection, based on the undoubted fact that ears having 10, 14, 18, and 22 rows are common, is pertinent but not insurmountable, for the commonest feature of corn and its relatives is one of abortion or suppression of parts. Leaf blades, branches, spikelets, and flowers are regularly aborted or rather suppressed, and the suppression of a single row of paired spikelets is sufficient to reduce a 12- to a 10-rowed ear. This suppression of rows of paired spikelets is a commonplace in most cornfields. Indeed, ears that begin with eight rows often through poor growing conditions end as six-rowed ears and even as four-rowed ones (pl. 24). The phenomenon is common in ears having higher numbers of kernel rows.

Although wholesale abortion is not a very satisfactory explanation on which to base theories, it cannot be ignored in considering the origin of the ear. Those who reject the fasciation, branch suppression, or yoked spikelet explanation of the origin of the ear are left with the theory that the ear, like Topsy, just developed.

In the present state of knowledge of the corn plant the idea of the origin of the central spike of the tassel by the suppression of branches offers the most reasonable explanation of this organ, and once given the central spike, the ear can be derived without further controversy.

What caused the suppression of the branches of the tassel, if in fact that is what happened, and what species of grass had the branches suppressed is an entirely separate problem. Nor is there any solution of why in maize both members of the paired female spikelets develop while in all other members of the tribe one member of each pair is suppressed. Here, too, there are several theories. One school of thought has corn derived from teosinte by gradual evolution aided in its later stages by man. Allied to this explanation is the suggestion that maize originated from teosinte by mutation or a series of mutations. The essential difference between origin by mutation and origin by evolution and selection is one of the magnitude of the stages. If the mutations were many and of small effect there is no difference between the two, but if maize sprang fullfledged as a single mutation from teosinte the two theories are quite divergent. A second group holds that corn and teosinte developed from a plant something like gama grass, the two genera splitting off from this common stem. The proponents of this theory hold that the line which developed into maize consisted of plants more maizelike than teosinte but still able to survive as wild plants. Their usefulness to man stimulated selection, and eventually the wild plants disappeared presumably to confound the students of maize. A third suggestion has been made that maize has been developed from a chance hybrid of teosinte and some other grass not specified but indicated as probably belonging to the sorghum tribe. Each of these theories has merit though none offers a satisfactory explanation of all the facts.

The floral unit of the grass family is the spikelet, and in the tribe of which maize is a member, the male spikelets are borne in pairs, one stalked, or pediceled, the other without a stalk, or sessile, each spikelet containing two flowers. The female spikelets of all the maize relatives are borne singly and are one-flowered—one whole spikelet and one flower having been suppressed, but in maize the female spikelets are still paired, though normally each develops but a single flower, which explains why the number of rows of kernels on an ear are found in multiples of two.

The seeds of most kinds of maize are naked, the glumes of the female spikelets having become greatly reduced in size and membranaceous in texture. There is one exception to this condition—the kind of corn called pod corn where each seed is enclosed in glumes which in some strains are grotesquely enlarged (pl. 25, fig. 1). It was thought at one time that this type of corn represented the ancestral or primitive maize. When moderately developed, the glumes of pod corn represent a less specialized condition, and hence a more primitive form, than the membranaceous glumes of the ordinary types of corn. However, it does not follow that pod corn is the primitive maize. It has been shown that this peculiar type does not breed true and can only survive as a hybrid with the normal form. Apparently the pure form of pod corn is sterile—not a very satisfactory condition for an ancestor. It is true that the podded condition is dominant to the usual form, in hybrids between the two, and most wild types are dominant to the derived forms. Also the cobs of pod corn easily become broken, tending to separate the protected seeds, thus aiding somewhat in their distribution. Despite the possession of these attributes of a wild plant, pod corn seems no more able to persist unaided than the familiar nonpod forms. Further, when it is crossed with a form of maize having the primitive condition of branched ears, the combination, instead of reconstituting a type of maize suitable for survival in the wild, gives rise to a sterile monstrosity aptly called cauliflower (pl. 25, fig. 2). Pod corn therefore, though possessing a few primitive features, must be classed with that host of misfits and abnormalities of which there are scores in maize brought about by changes in the ordinary heritable elements or genes.

All of the relatives of maize have the seeds enclosed in glumes, and in some the outer glume has been thickened to cover the seed, which is deeply embedded in a cavity, or alveolus, in the rachis. Other maize relatives such as *Coix*, have the seed completely enclosed in a greatly modified leaf sheath, shell-like in texture. These modifications place the relatives of maize farther up the evolutionary tree than maize itself and offer serious obstacles to the theory that corn has been developed from its existing relatives by selection.

Further, maize is much less stable than its relatives in the separation of the sexes—the basic characteristic of the tribe to which it belongs. The development of female flowers in the tassel or of male flowers on the ear of maize is a commonplace, and many true breeding forms of this sort are known (pl. 26, fig. 1). In the relatives of maize such aberrations are practically unknown, evolution in these relatives of maize apparently having progressed to the point where the sexes are completely separated.

The characteristics that differentiate maize from its relatives are all in the direction of fashioning a plant useful to man. The large seeds, much larger than is required for the full nourishment of the young seedling, the ear of kernels whereby all the seeds are securely fastened in one or two packages, the loss of a dispersion system extending even to the male panicle, the brachytic lateral branches and suppression or total loss of buds, in the axils of the leaves other than at the ear nodes, are all features fitting the plant to man's requirements and unfitting it for independence. Clearly then it is logical to conclude that these attributes are the result of man's efforts. It would be as unreasonable to ascribe them to fortuitous variation as to accredit them to a beneficent providence.

Before man could initiate the selection which some authorities believe eventually led to maize there would have to be some encouraging characteristic, some useful part, on the plant with which he started. Now no more useless grasses from the standpoint of human consumption could be devised than the American relatives of maize. The seeds of teosinte, the most maizelike relative, are no larger than a No. 4 shot, are firmly embedded in a brittle articulated rachis and are further protected by a hard shell-like outer glume (pl. 26, fig. 2). They have the added disadvantage of being distributed throughout the plant in spikes of only six or seven that ripen over an extended period. The labor of gathering and the difficulty of separating enough seeds from their covering to furnish a day's food supply would be disheartening, especially with other more promising grasses from which to choose a cereal food.

There is no evidence among the earliest burials that teosinte was ever used despite the fact that the "seeds" are almost ideally adapted to long preservation. Further, had this plant served as human food the changes that would have been wrought by selection can be visualized. Almost certainly the seeds would have increased in size, probably to the point of extending beyond the outer glume and protruding from the rachis cavity. The spike would have been stiffened, and the rachis segments would have become firmly united. The outer glume might have become soft, and the number of seeds in a spike would have increased. None of these changes would have led to maize but to a domesticated form of teosinte clearly exhibiting its mode of origin just as the domesticated forms of the Asiatic maize relative, *Coix*, resemble their wild ancestor. Such a hypothetical cereal as the domesticated teosinte we have sketched would be further removed from the wild plant than are the domesticated forms of *Coix*, which gives some idea of the time factor required.

Of course, given time enough, it must be granted that maize could arise from teosinte by selection just as the troupe of monkeys pounding at random on the keys of the typewriter would in time reproduce the works of Shakespeare. This period of time, however, is believed to be excessive.

The mutation theory affords an easy means of overcoming the time factor since by assuming a single mutation it is possible to originate maize from teosinte or for that matter from any other grass within a single year. Of course, no one proposes that maize arose in quite this abrupt fashion. However, it has been suggested that maize arose through a series of mutations, each leading to a more maize-like plant. Thus, if a mutation took place in teosinte such that seeds of useful size were produced, man would immediately enter the picture to preserve such plants. In time a second mutation might produce paired female spikelets such as are found in corn, and by further mutations a cob could have been derived, and so on until all the differences between maize and teosinte were obtained. These mutations need not have been gross changes but each one preserved must have increased the value of the plant to man.

The evidence against anything approaching the origin of maize through the preservation of relatively large mutations is threefold. First, none of the intermediate stages, none of the halfway corns, have been found in the earliest burials. This is a minor objection if the mutations took place in remote times but it is well to bear in mind because perforce it places man in the New World in very ancient times. Not so ancient it is true as would be required if corn were derived from teosinte by the orthodox means of selecting small variations or small mutations, but measurable in thousands of years.

Second, corn everywhere is botanically identical. The corn of North America is indistinguishable in the features which make it corn from that of South America. For those who hypothecate a relatively few major mutations this hemispheric identity of corn is unfortunate. The first mutation making teosinte or any other corn ancestor useful to man would have started the plant upon its journeys, and the succeeding mutations that led to the building up of maize would have occurred at widely scattered points and over centuries of time. Each would spread from its point of origin but different combinations of these mutations would be expected at different points on the periphery of corn distribution. Widely separated regions of the New World would have had widely different species of corn. We have seen that such is not the case. To account for the obvious fact that corn is corn wherever found we must assume either that enough time has elapsed since the last important mutations to permit them to have become thoroughly incorporated in the species or the less likely assumption can be made that all the mutations eventually occurred at some one place and the plant was distributed from that point.

Although mutations have not been found in teosinte today, no doubt they do occur but not of an order of magnitude that would suggest a development into maize.

In maize, mutations are almost the rule, the germ plasm being in a highly unstable condition as compared with that of its wild relatives. Within the past 20 years over 300 heritable variations or mutations have been discovered and the nature of their inheritance determined. Some of these affect the structure and appearance of the entire plant, and if considered strictly from a systematic botanical point of view, plants possessing certain ones of these mutated genes could not be classed as maize but would fall more naturally into the sorghum tribe. Indeed the mutation known as teopod, the result of a change or mutation in a single gene, is of sufficient magnitude to give to the origin of maize by mutation strong superficial support in that it illustrates what profound modifications can occur as the result of a single gene change (pl. 27).

The most serious objection to the hypothesis that maize originated from teosinte by mutation is found in a study of the hybrids between these two genera. The characters that differentiate the two genera do not behave in inheritance like mutations. The ear of corn does not segregate as a unit or a few units from teosinte-corn crosses and so with the other characters (pls. 28 and 29). These hybrids show clearly that the two genera differ by hundreds if not thousands of genes or on the mutation idea that corn differs from teosinte not by a few major mutations but by a multitude of small ones. This fact reduces the mutation theory of origin to that of the selection of small variations. In reality there is no difference between the two theories for mutations vary in their effects, some gene changes leading to gross modifications of the plant, others leading to infinitesimal effects, and the two theories become theories regarding the length of time involved in the process of changing teosinte to corn.

If corn has been developed from teosinte by the selection of hundreds of favorable fortuitous gene changes the period of time involved is such that the complete interfertility of the two genera needs explanation, for in such vast periods of time incompatibilities should have arisen in chromosome configuration such as translocations, inversions, deletions, polysomics, and polyploids that would have limited conjugation and resulted in sterility. The first explanation of the persisting fertility of these genera when hybridized is that they have remained an interbreeding group from the beginning with man ever preserving corn, nature preserving teosinte, while the intermediates fell by the wayside. Aside from the fantastic nature of this assumption, it finds a contradiction in the morphology of the chromosomes of the two genera.

When observed at the appropriate stage of cell division the chromosomes of both teosinte and of corn are seen to have distinctive enlargements, globose in shape, distributed along their length. These swellings have been termed "knobs" and they are becoming very useful in the identification of individual chromosomes as they pass from one parent to another in hybrids (pl. 30, fig. 1).

In teosinte, knobs are found only on the ends of the chromosomes, or, as in the perennial species (*Euchlaena perennis*), they may be so small and indistinct as to be practically nonexistent. In maize, these knobs occur at various locations along the chromosome but they are not found on the ends.

These two closely related genera, then, are differentiated by the one having terminal knobs and the other having internal knobs on their chromosomes. Now there is no known mechanism whereby the chromosomes of corn can mate with those of teosinte, generation after generation, without exchanging segments. If such exchanges have taken place over the years, then no such differences in chromosome morphology as have been observed should be found. The conclusion must be reached that no such widespread interbreeding has been taking place unless it is assumed that all of the qualities that constitute a teosinte plant as distinct from those that make corn are located in or very close to the knobs. To be even remotely reasonable this assumption would require far more knobs than are found. Further, such repeated interbreeding even with strict selection would, in time, have made the members of the two genera much more alike than they are.

The third theory of the origin of maize through the hybridization of teosinte and some unspecified grass having some of the characteristics of the sorghum tribe composes some of the conflicts met in the other theories of origin, but raises additional ones. It derives its support from the obvious fact that the nearest known wild relatives of maize possess only some of the features of maize, lack others entirely, and are more highly specialized in still other characteristics. Thus the seed spike of teosinte with its single instead of paired spikelets and its hardened shell-like outer glume protecting the seed hidden in the hollowed stem, or rachis, is in these respects more highly specialized than the ear of corn. Then, too, maize flowers in the long days of summer and is insensitive to alterations in the length of day, whereas teosinte is extremely responsive to day length and flowers promptly when subjected to a short period of daylight.

Given a parent which would bring into a hybrid some of the characters possessed by maize and not by teosinte it would be possible to derive maize within a period of time such that the interfertility of the hybrid derivative with its parents was not lost. It would also be possible to account for some of the chromosome morphology and would explain the great variation and unstable germ plasm of corn. Undoubtedly corn possesses many characters that relate it to the sorghum tribe, many more in fact than any of its relatives, but the possession of these obvious affinities with the Andropogoneae does not establish a parent and offspring relationship. These two great tribes of grasses are clearly related, so that for the members of one to have some characteristics of the other is no more than is to be expected even though the relationship is distant.

The chief objection to the origin of corn by the hybridization of its known wild relatives with some other grass lies in the uncertainty of what grass constituted the other parent. The sorghum tribe is made up largely of Old World grasses, none of which were known to have been introduced into the New World until quite recently. So far as is now known none of the members of the sorghum tribe has chromosomes that resemble those found in maize, though the two tribes have identical chromosome numbers. Further attempts to hybridize corn and sorghum and sorghum and teosinte have failed repeatedly.

This failure to obtain hybrids, however, may merely mean that the proper conditions or the proper parents have not been tried. Hypothecating an unknown parent, is not greatly different from concluding that maize developed from a wild form now extinct except that it does not close the door so effectively against the possibility of recreating maize. The time factor required to stabilize the hybrid and distribute the finished product throughout the New World would probably be somewhat less than that required on the rejected hypothesis of major mutations but either would require a very long time.

Aside from the fact that it begs the question, the belief that maize was domesticated from a pre-maize species by selection leaves wholly unexplained the interfertility of maize and teosinte, if the relationship of these genera is so remote they would not be expected to produce fertile offspring when crossed. It also has all of the defects of the mutation theory in respect to the lack of evidence of primitive maize in the earliest burials. Further, teosinte so far as tested seems to have allelomorphs of the identified genes of maize. In some cases not only are the dominant allelomorphs of the maize genes present in teosinte but they are accompanied by modifying genes and in other cases teosinte possesses genes recessive to those dominant in maize. Clearly, the relationship of these genera is intimate, but whether they stand in the relation of parent and offspring cannot now be determined.

If teosinte and maize are on widely different branches of the corn family tree, as the hypothesis of the development of corn from an extinct cornlike ancestor requires, it would be expected that hybrids between the two genera would be intermediate in nature. Genes which in maize have a clear-cut dominant and recessive reaction should behave as intermediates without clear-cut dominance when mated with their allelomorphs in teosinte. This expectation follows from the explanation of the origin of dominance through the accumulation of genes tending to transform the intermediate condition exhibited in organisms heterozygous for mutated and unmutated genes into that produced by the most favorable gene combination. Thus, if a tall plant mutated to a short one and the combination of the two was intermediate and less favorable than the short, then in time, through the gradual accumulation of supplementary genes, short plants would come to be dominant to tall ones. If, on the other hand, tall was the favorable size then in time tall would become dominant and the two genes, tall and short, that in the beginning gave in the segregating generations a ratio of one tall to two intermediate to one short would give three tall to one short.

For selection to operate to accumulate conditioning factors for mutated genes the two gene forms must be brought together. If a gene change occurred within a species this changed gene when introduced into another species where no such change had taken place should give an intermediate first generation and exhibit a 1–2–1 segregation in the second generation. However, if the two species were not widely separated and intercrossing had occurred permitting both species to accumulate the necessary conditioning factors then the reaction should be one of clear-cut dominance.

As is often the case when promising leads reach an impasse, a combination of all of them offers hope of further progress and the origin of maize may involve all the processes suggested—selection, mutation, hybridization—and also an extinct plant having characteristics complementing those of teosinte but not of sufficient merit from the standpoint of man to have entered into his diet. By the accidental hybridization of teosinte or some mutations of teosinte with some such grass a plant useful to man could result. This hybrid need not have occurred often but selection of the fluid germ plasm resulting could produce a new cereal relatively rapidly.

Even under this combination of processes maize stands as having been created and fixed botanically at such a remote period that one and only one sort of maize became established over the Americas leaving no trace of its intermediate forms. Naturally, if hybridization was an important factor in the development of maize, the center of origin was very circumscribed, for presumably such chance hybrids were not of common occurrence. Under this limitation the new hybrid may have been fashioned into maize rapidly by means of selection without starting a chain of distribution of pre-maizelike plants. The distribution would not have begun or would not have gone far until the main characteristics of corn were fixed. This would accord well with the evidence on the distribution of maize.

Whatever explanation is finally proved to be correct, everyone agrees that in the form we know it today maize is the result of man's skillful efforts. Whether it was derived from a hybrid, an extinct plant, a mutation from teosinte, or by orthodox selection, generations of patience and of plant genius went into its formation. The American Indian molded his plant material to a higher degree of perfection than the plant domesticators of the Old World did their cereals, possibly because his interests were not divided between plants and animals. Whatever the secret of his success, he created the world's most highly developed grain, and that his task was well done is proved by the wealth added annually by his creation not only in the New World but in the Old World as well.

Since the occupation of the Americas by the Europeans no real change has been made in corn except to discard the gaudy colors of the seeds and to establish a greater uniformity by the preservation of the best of the Indian's product. True, the dent type of corn which forms the basis of our Corn Belt varieties probably has arisen through hybridization of the flint and gourd seed types, the latter known to the Indians as She corn. We have not even modified the Indian's cultural system of growing the plants in hills though we have adapted his system to our machines.

With the stimulus to experimental heredity that came at the beginning of the century, on the rediscovery of Mendel's principles, corn rapidly assumed a leading role as a subject ideally suited for the study of inheritance in plants.

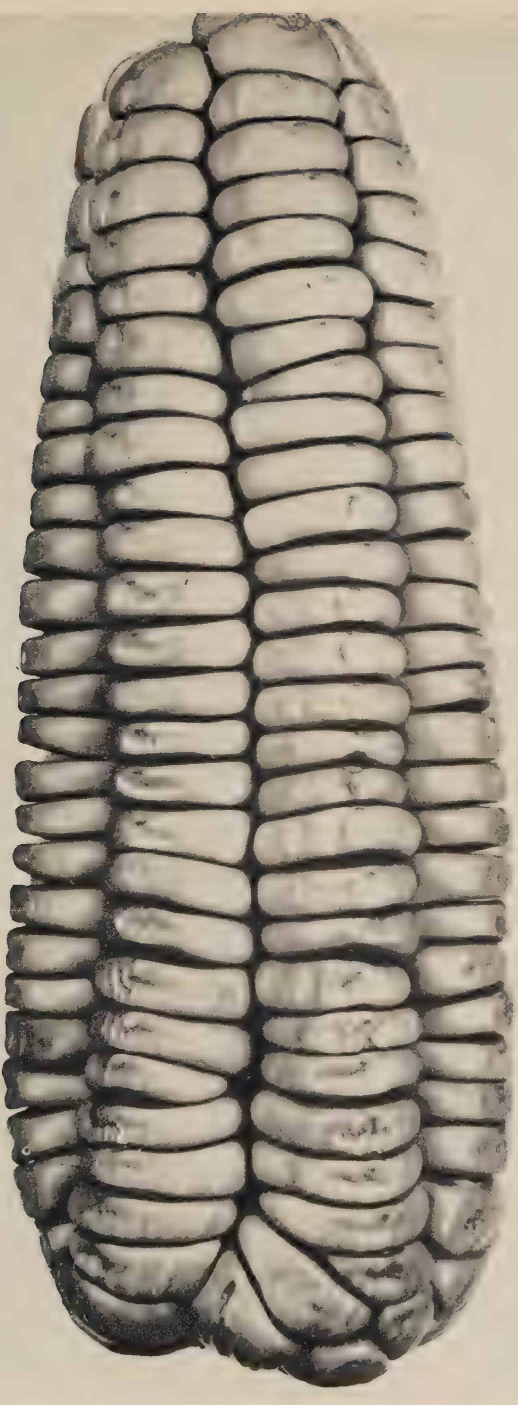
Had the Indian creators of corn anticipated such studies they hardly could have fashioned a more satisfactory plant. Controlled pollinations are made with the greatest of ease because of the separation of the sexes, the complete receptiveness of the stigmas over their entire length, and the vast quantities of pollen produced by a single plant. Common grocer's paper bags and string are the only really essential technical equipment necessary to embark upon the fascinating analysis of the transmission of traits from one generation to the next. Of course, the experts have added frills to this equipment chiefly as a means of labor saving in the interests of greater speed and better controlled pollinations. Not only is the technic of crossing most simple but the number of offspring obtained from a single pollination reaches as many as a thousand or more, a very great advantage for studies of this nature.

Added to the advantages of numerous offspring there is the additional feature that the seeds came supplied with numerous readily classified characters to which may be added a host of seedling traits. The possibility of obtaining numerous progeny from a single mating embracing many readily classified characters almost offsets the one great disadvantage of but a single generation in a year. By the time the characters already awaiting study had been analyzed, the amazing corn plant had obligingly provided a host of new mutations until at the present time the inheritance of some 350 genes is known and the end is not in sight. The flexibility of this plant is nothing short of astounding, and each year finds more mutations awaiting analysis.

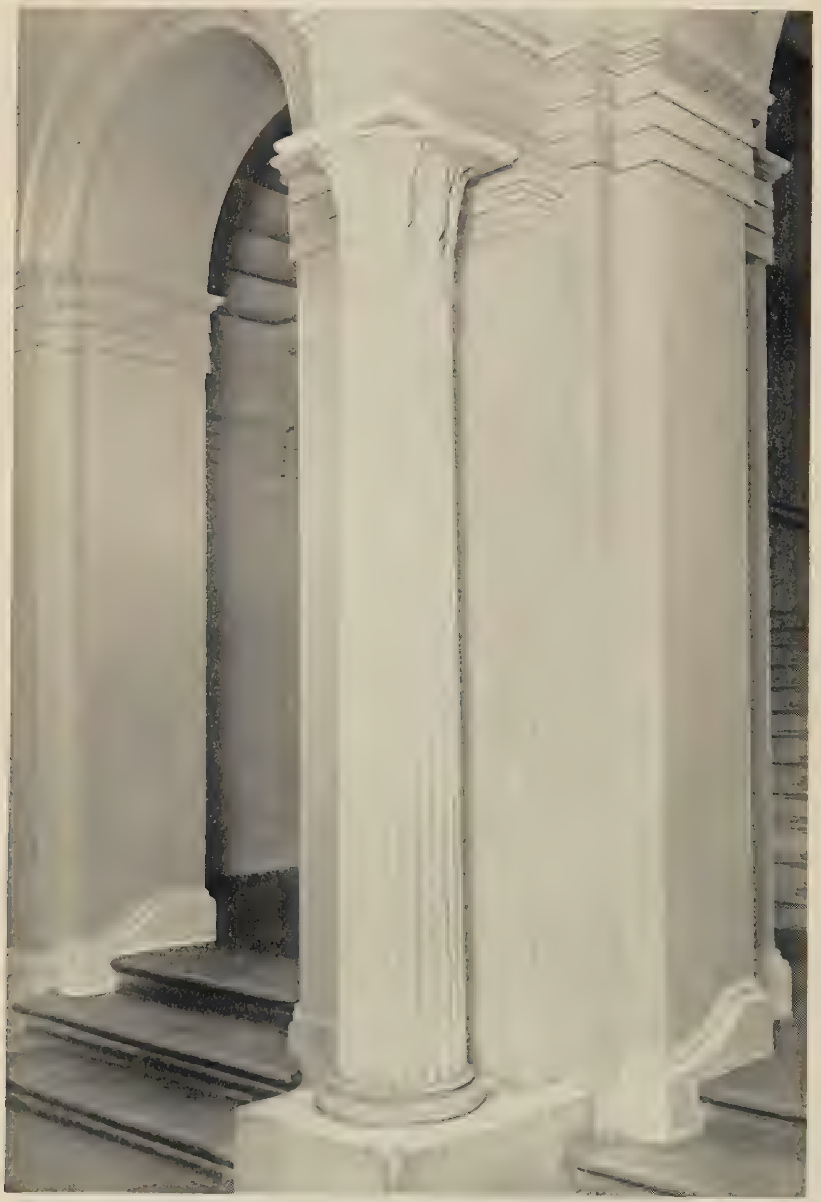
The heritable units thus far studied affect all parts of the organism ranging from genes that exhibit their reactions only in the pollen grains, through seed and seedling characters, to those that alter the entire plant. There are genes that change all the female flowers to males (pl. 30, fig. 2), others that reverse this process to the same end and change all male flowers to females. Others undo the separation of the sexes and make the plant perfect-flowered.

These changes, interesting from the standpoint of heredity, are also of interest in view of the uncertain antecedents of corn. The possession of numerous genes that profoundly modify sex expression suggests that maize may have, not far back in its descent, a perfect-flowered ancestor. From existing knowledge of inheritance it has been possible to create true breeding strains having male and female plants in equal numbers and capable of self-perpetuation. It is also possible to develop a perfect-flowered form of maize with the seeds borne on the familiar tassel instead of on an ear and which, if combined with some of the genes for dwarf stalks, would produce a crop that could be harvested with a combine just as is wheat or the dwarf forms of grain sorghum.

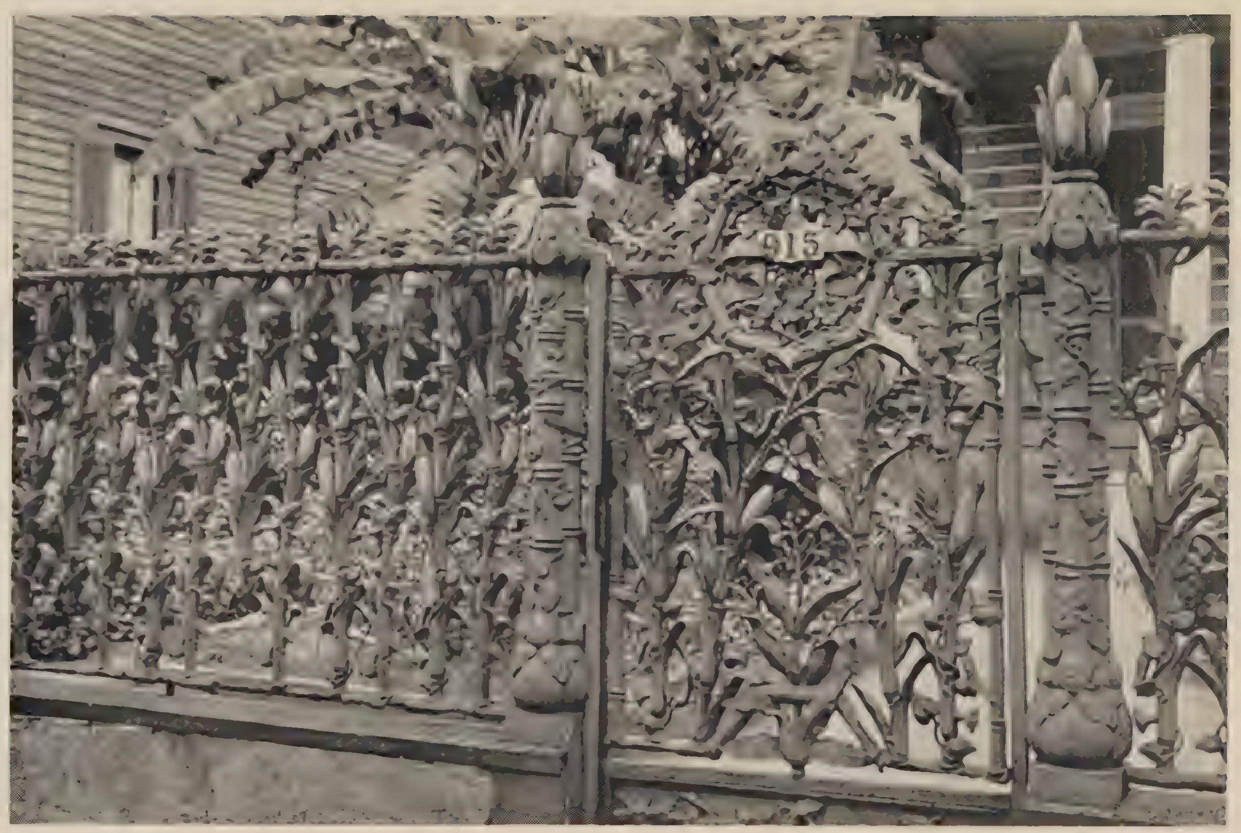
The possibility of improving upon our heritage from the Indians is very real and is commanding the attention of an active group. Even now, through the stimulation derived from a purely theoretical extension of our knowledge of inheritance, hybrids far surpassing the best varieties have been obtained and a system devised for their commercial use. That the future holds even greater things for corn with the increase in knowledge of gene interaction is a certainty.



AN EAR OF CUZCO CORN. (NATURAL SIZE.)

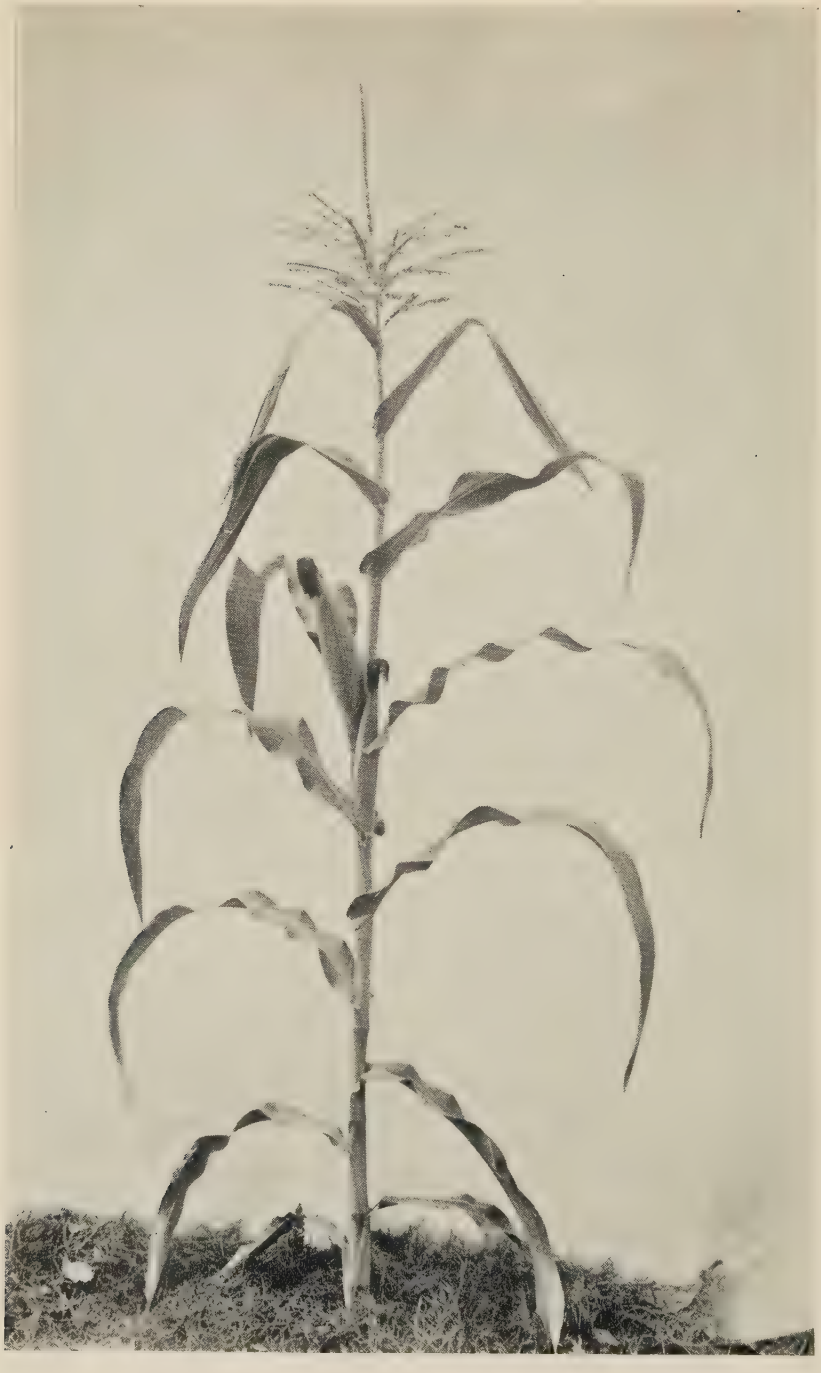


COLUMN IN THE CAPITOL AT WASHINGTON DESIGNED BY LATROBE SHOWING MAIZE MOTIF.



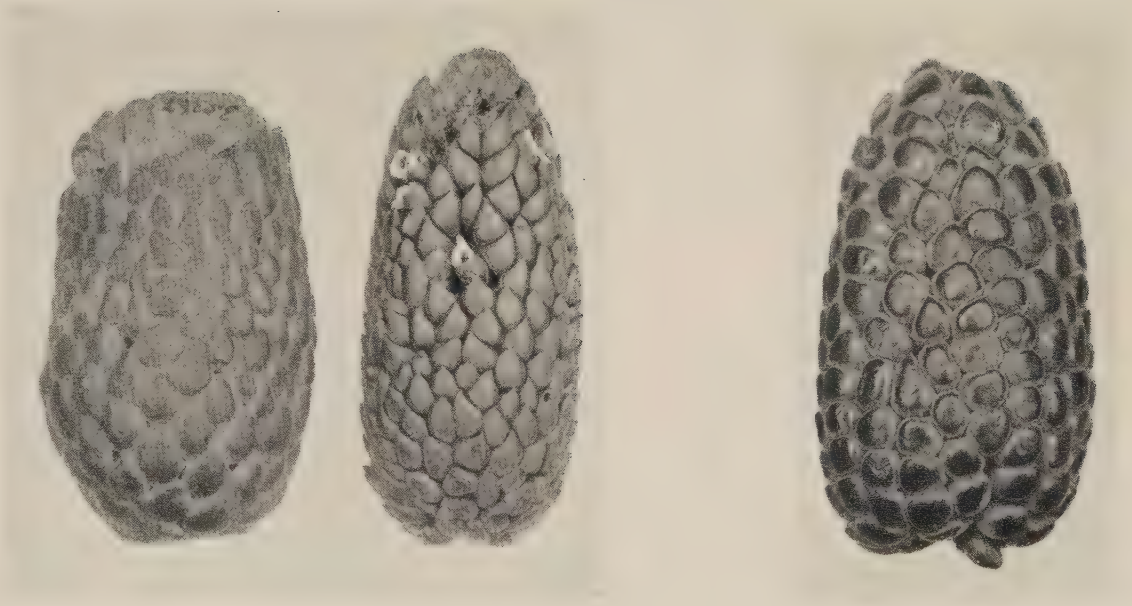
CAST IRON CORN FENCE IN OLD NEW ORLEANS.

In designing this fence the planters were careful to include the curse of Southern corn growers—bindweed—that will be seen twining around the cast iron stalks.



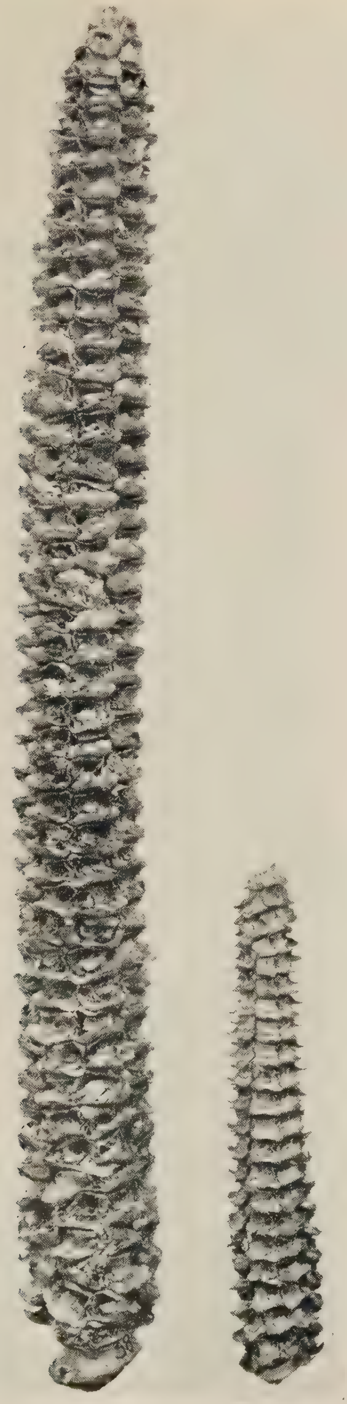
A NORMAL CORN PLANT SHOWING THE CHARACTERISTIC FEATURES OF THIS SPECIES, THE PRONOUNCED CENTRAL SPIKE OF THE TASSEL AND THE EAR BORNE IN THE AXIL OF THE FIFTH LEAF FROM THE TOP.

The leaves above the ear have no buds in their axils and the buds in the axils of the leaves below the ear are suppressed.



EARS OF CORN FROM PERU

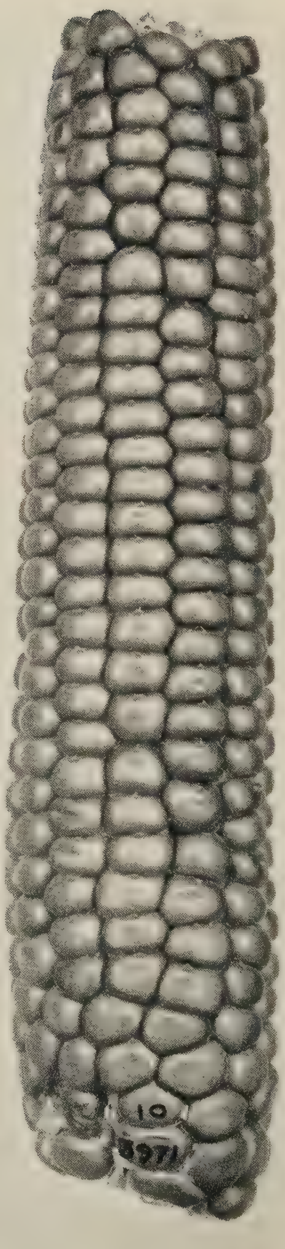
The ear at the right was grown within the past 10 years; that in the center was exhumed from a pre-Inca burial and is from 1,000 to 2,000 years of age. The object at the left is a clay replica of an ear that passed for a time as a fossil ear of corn. It was probably a leg from an ancient pot. (Natural size.)



G. G. Heye Museum of the American Indian

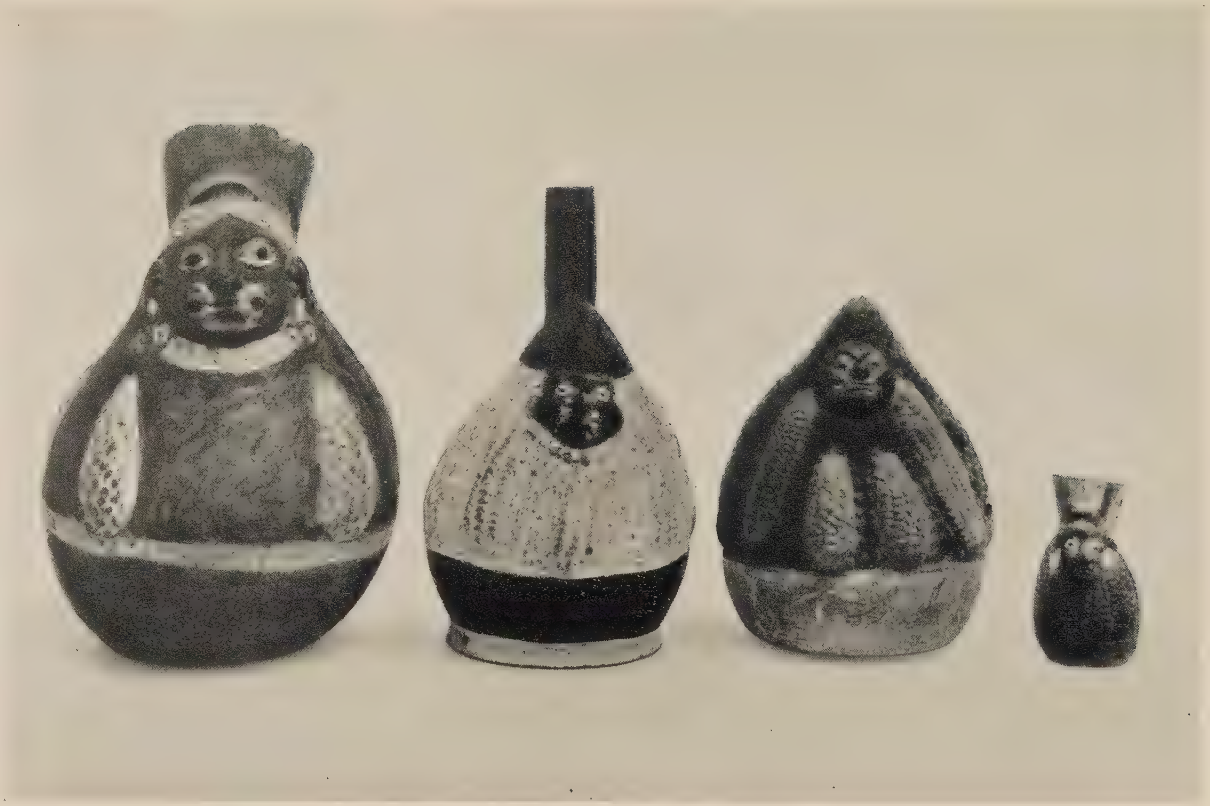
1. COBS OF MAIZE FROM THE CAVES OF THE OZARKS.

(Natural size.)

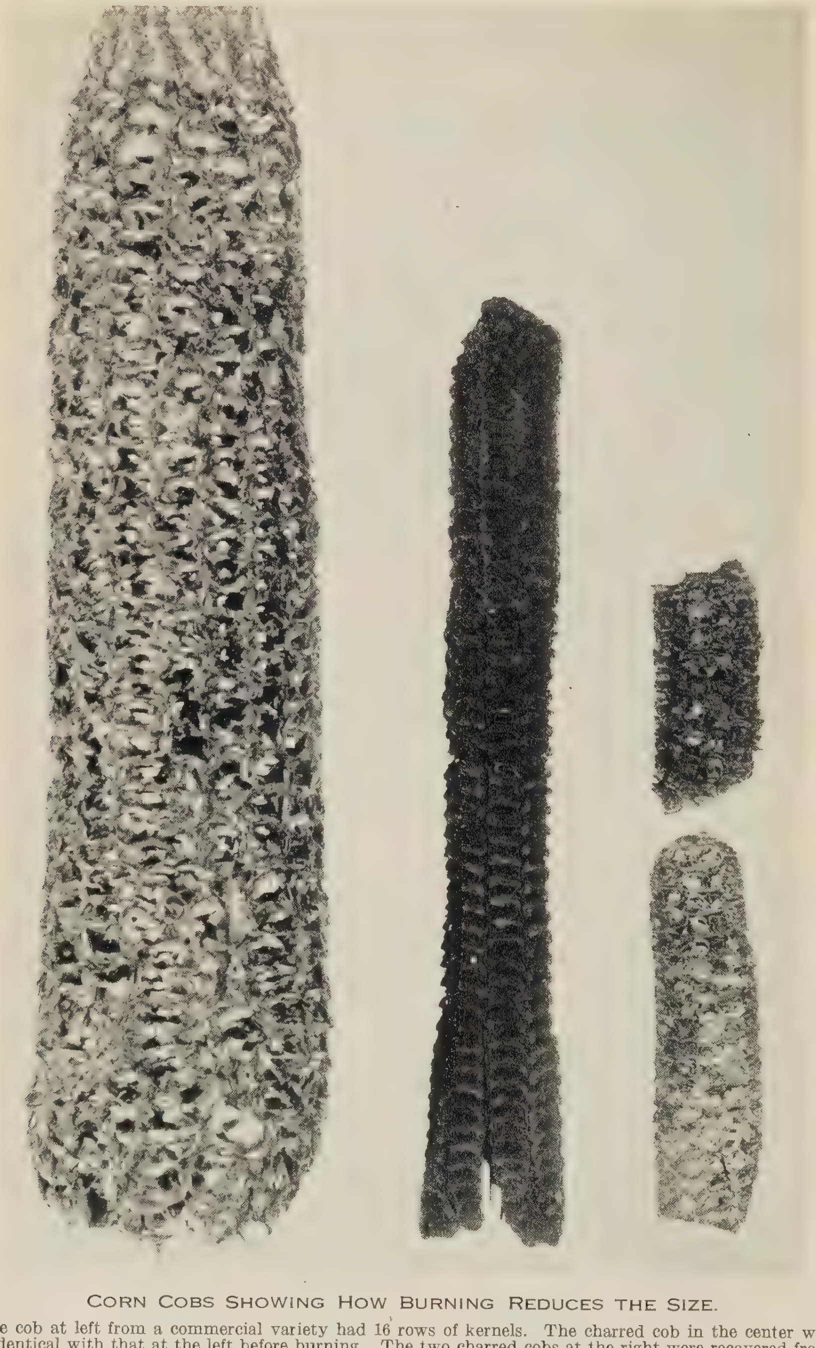


2. EAR OF CORN FROM CAVE DU PONT, UTAH.

These ears were grown by the Basket Makers who preceded the Cliff Dwellers. They may be a thousand years old.

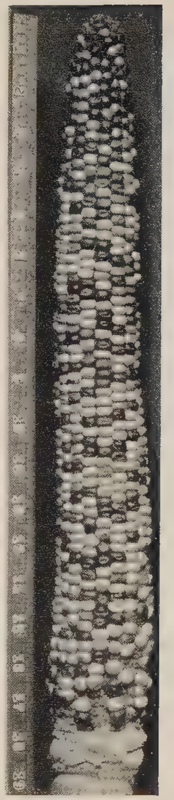


CORN POTS FROM PERUVIAN GRAVES SHOWING REPLICAS OF THE CORN OF THE ANCIENTS.



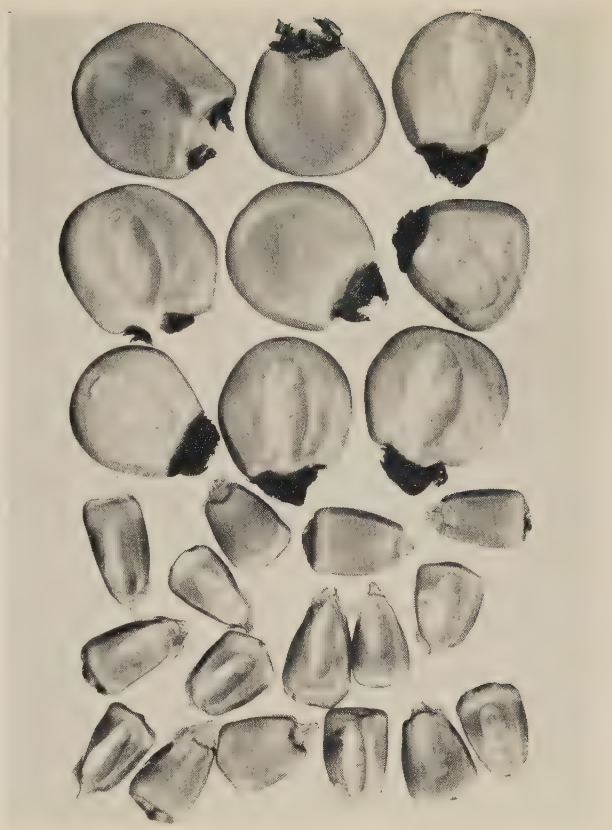
CORN COBS SHOWING HOW BURNING REDUCES THE SIZE.

The cob at left from a commercial variety had 16 rows of kernels. The charred cob in the center was identical with that at the left before burning. The two charred cobs at the right were recovered from a refuse heap in the Chaco Canyon of New Mexico and are approximately a thousand years old. (Natural size.)



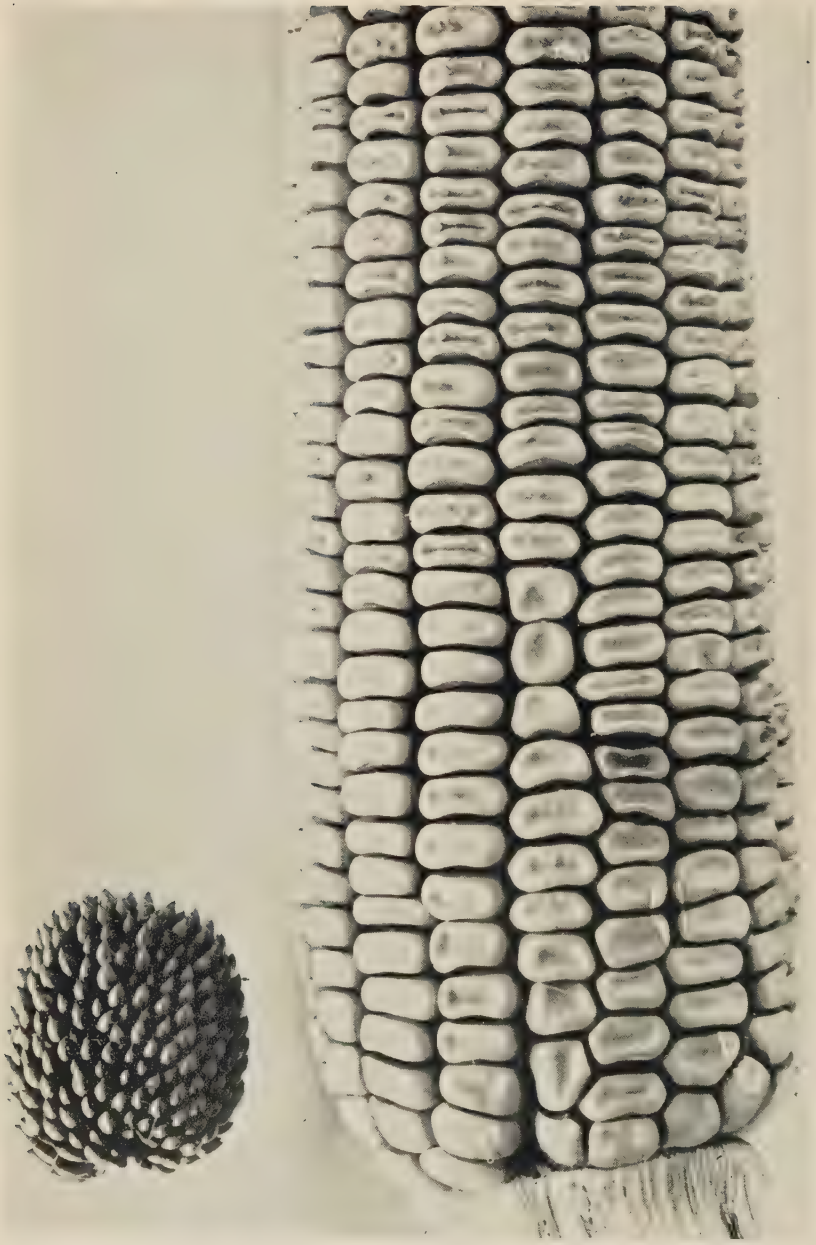
1. THE LONGEST EAR OF CORN KNOWN.

This ear was grown by a Navaho Indian in New Mexico a few years ago.



2. KERNELS OF CUZCO CORN COMPARED WITH THOSE OF OUR COMMERCIAL CORN BELT VARIETY, BOONE COUNTY WHITE.

(Natural size.)



A Comparison of the Smallest Ear of Normal Maize With a Section of One of the Larger Ears.

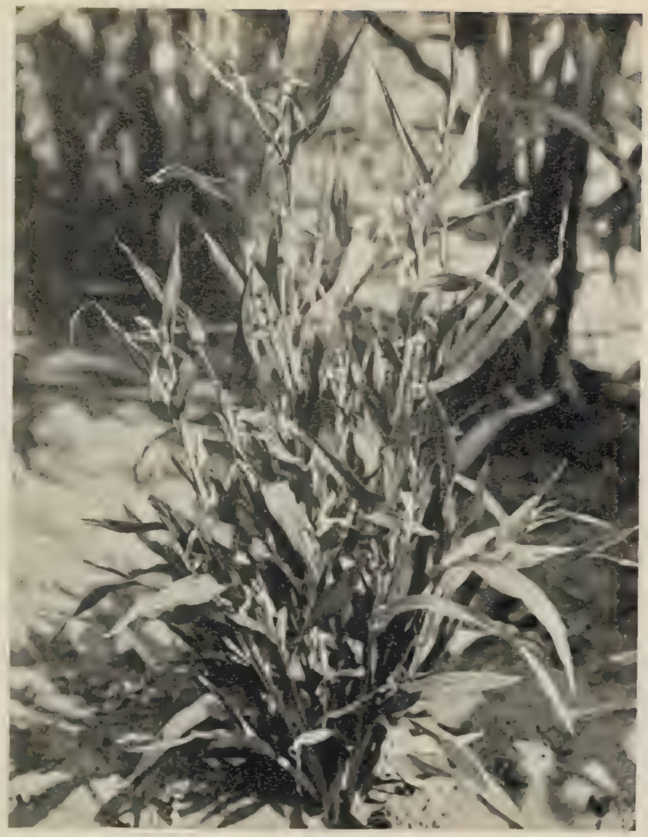
The small ear is from a variety of popcorn grown by the Peruvian Indians and the section is of a variety grown on the west coast of Mexico. (Natural size.)

1. CORN PLANTS GROWING IN CALIFORNIA FROM GUATEMALA SEED.

These are among the tallest plants known, the plants at the left being about the height of our Corn Belt varieties. The tallest plant showing is 18 feet.

2. CLUMP OF CORN SEEDLINGS SPRINGING FROM A BURIED EAR.

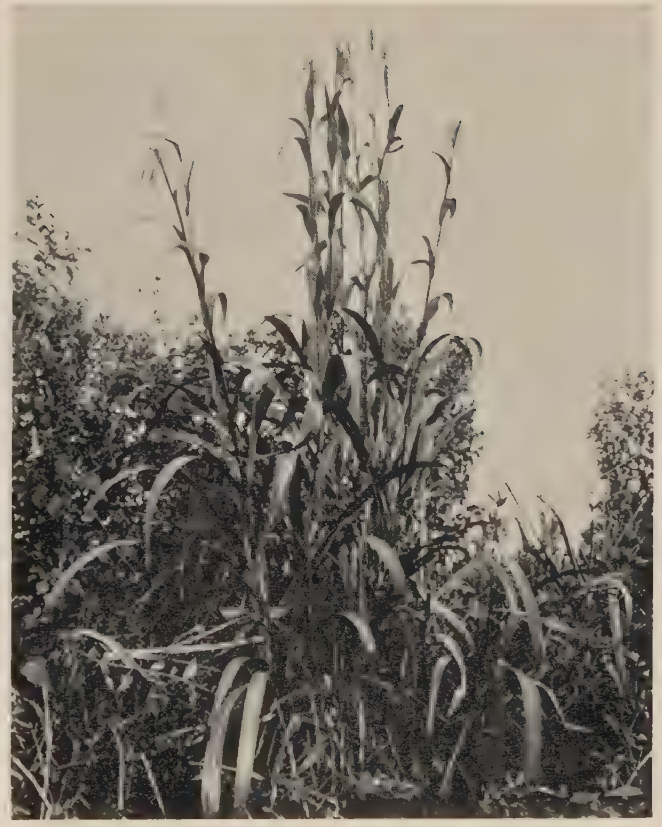
These seedlings, though kept free of weeds throughout the season, failed to produce seed for the next generation.



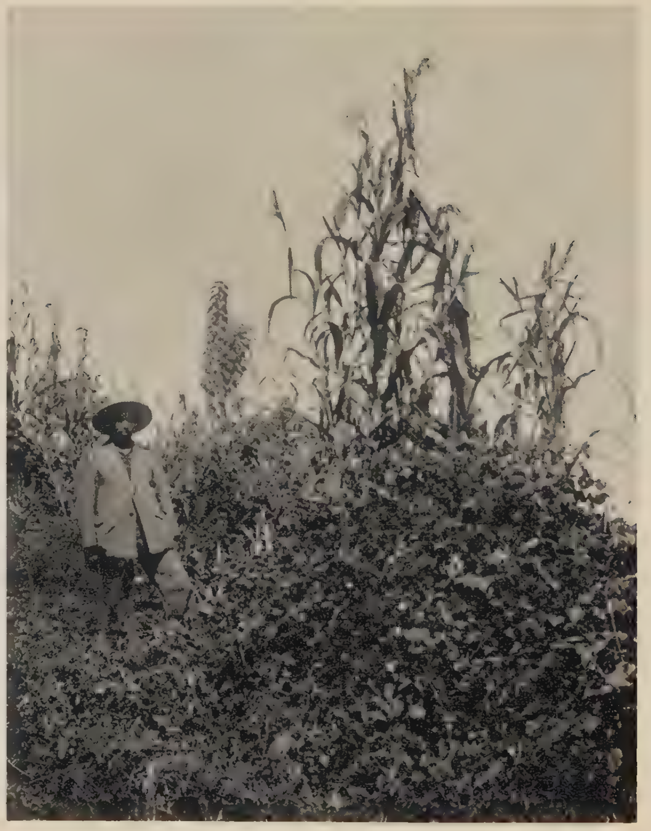
1. A Plant of Job's Tears (Coix lachryma jobi), the Most Widely Known Asiatic Member of the Maize Tribe.

2. Sorghum—An Old World Grass of the Tribe Andropogoneae.

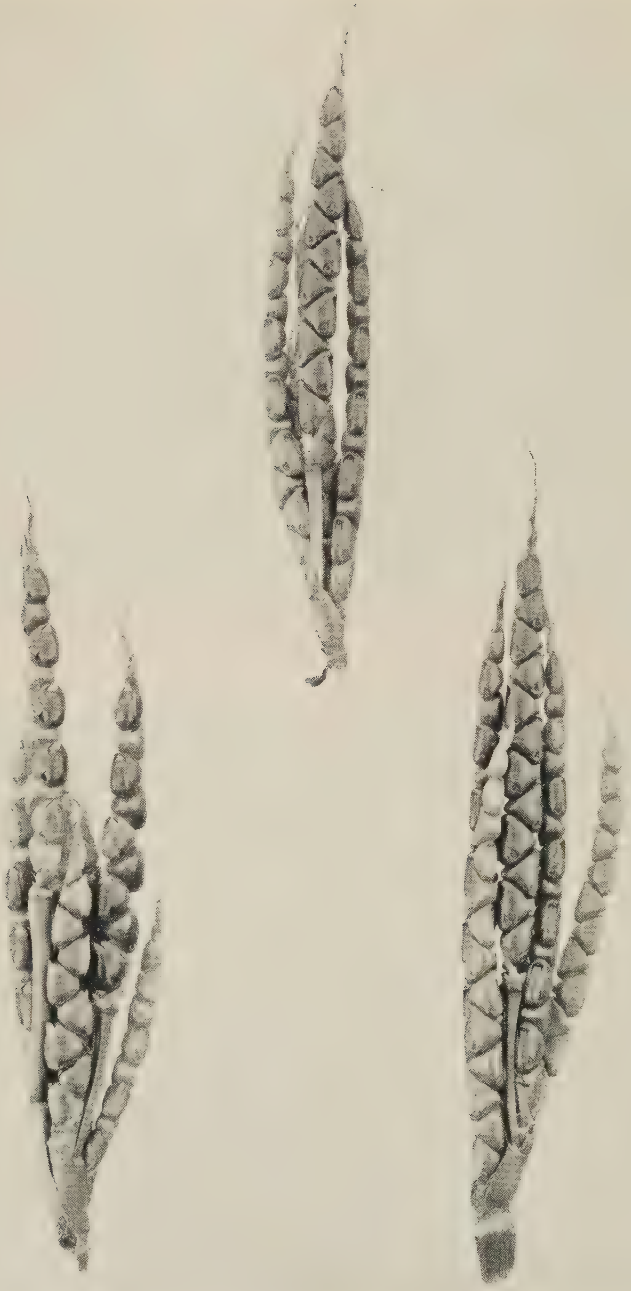
This tribe has many characteristics in common with Indian corn but it was introduced into the New World less than a century ago.



1. The Wild Relative of Maize. Gama Grass (Tripsacum pilosum), Growing on the West Coast of Mexico.

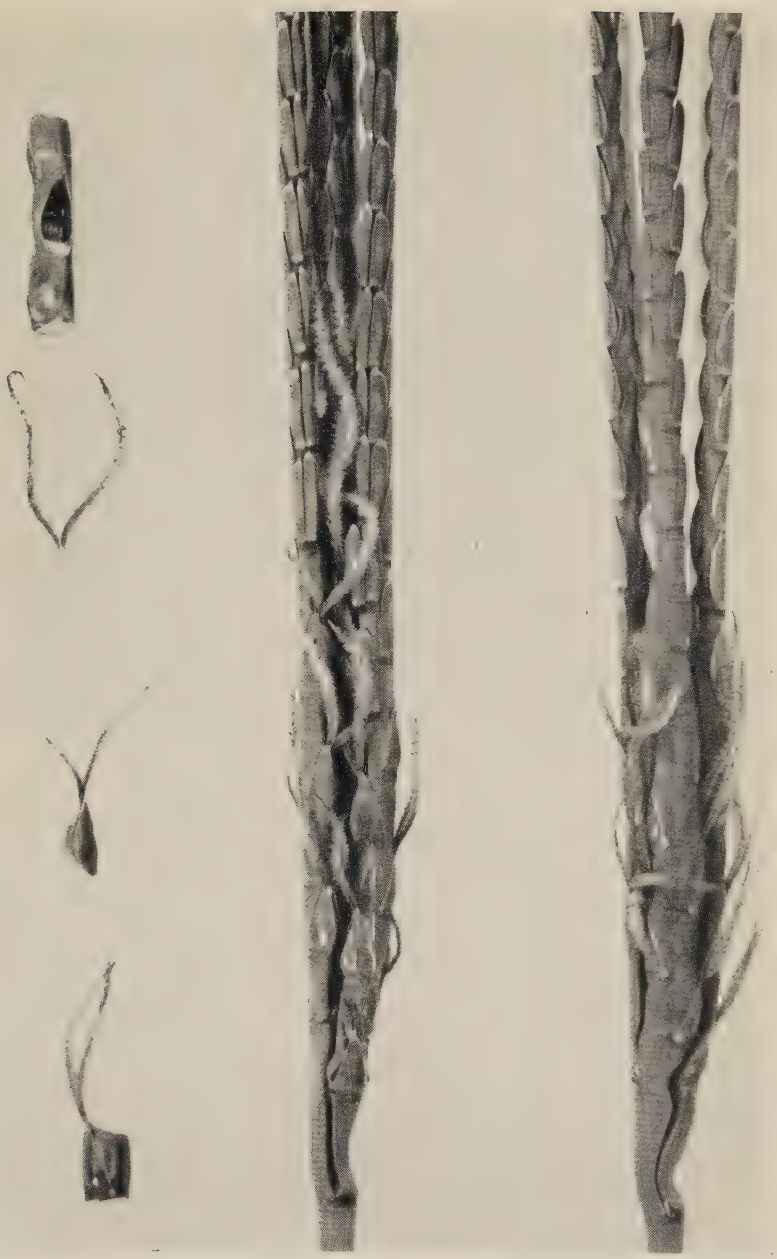


2. The Nearest Wild Relative of Maize. Teosinte (Euchlaena mexicana). Growing Wild Near San Antonio Huixta, Huehuetenango, Guatemala.



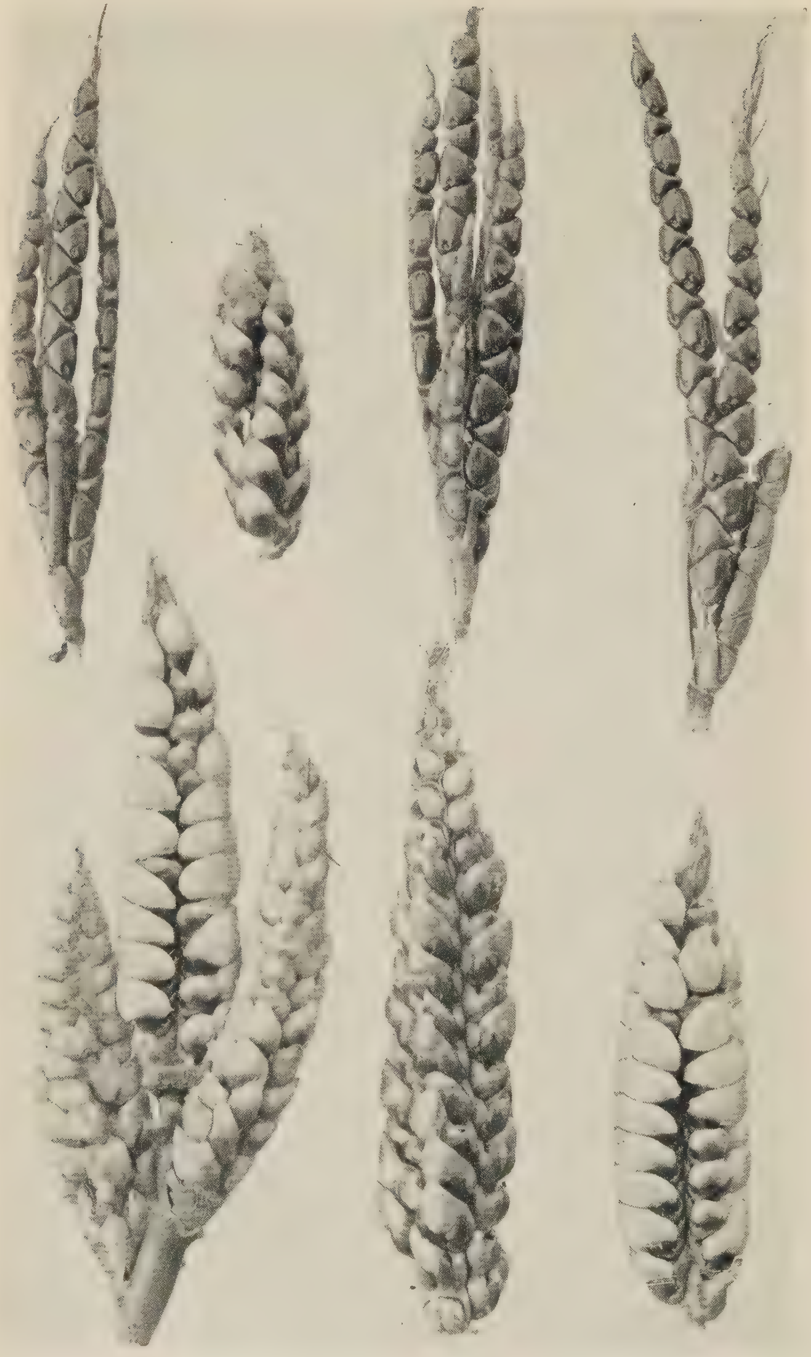
SEED SPIKES OF TEOSINTE (EUCHLAENA MEXICANA).

When growing, each spike of these clusters is enclosed in bracts comparable to the husks that envelop the ear of maize. These bracts have been removed to show the spikes. (Natural size.)



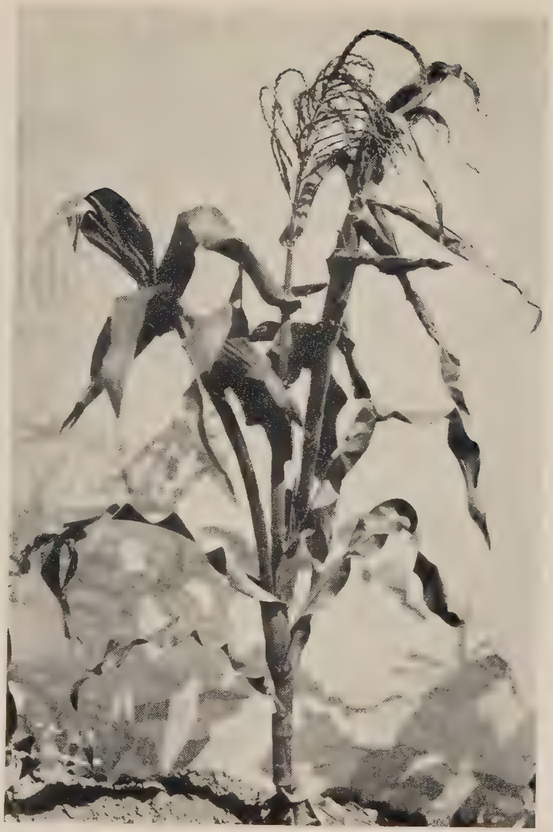
INFLORESCENCES OF THE WILD RELATIVE OF MAIZE, GAMA GRASS (TRIPSACUM DACTYLOIDES).

The seeds are borne at the base of the inflorescences, the upper sections of the branches bearing only male flowered spikelets. At the lower left is shown a segment of the rachis in which is enclosed the seed. Next above the female spikelet is shown removed from the enveloping rachis, and above that is the ovary freed from the glumes. At the top is shown the rachis cavity or alveolus in which the spikelet is embedded. (Natural size.)

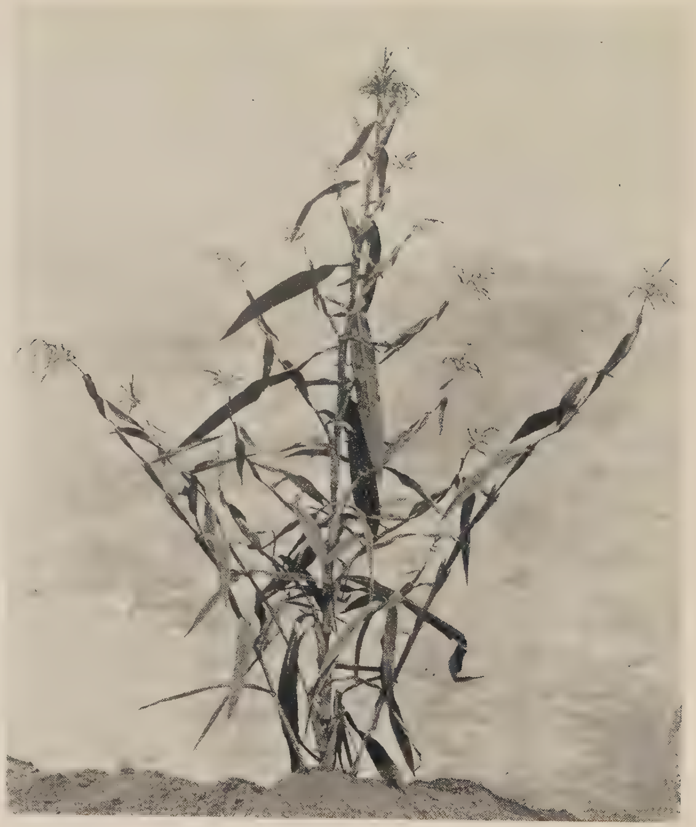


SPIKES OF TEOSINTE AND OF TEOSINTE-MAIZE HYBRIDS AS FOUND GROWING NATURALLY IN MEXICO.

Teosinte spikes at upper left. (Natural size.)

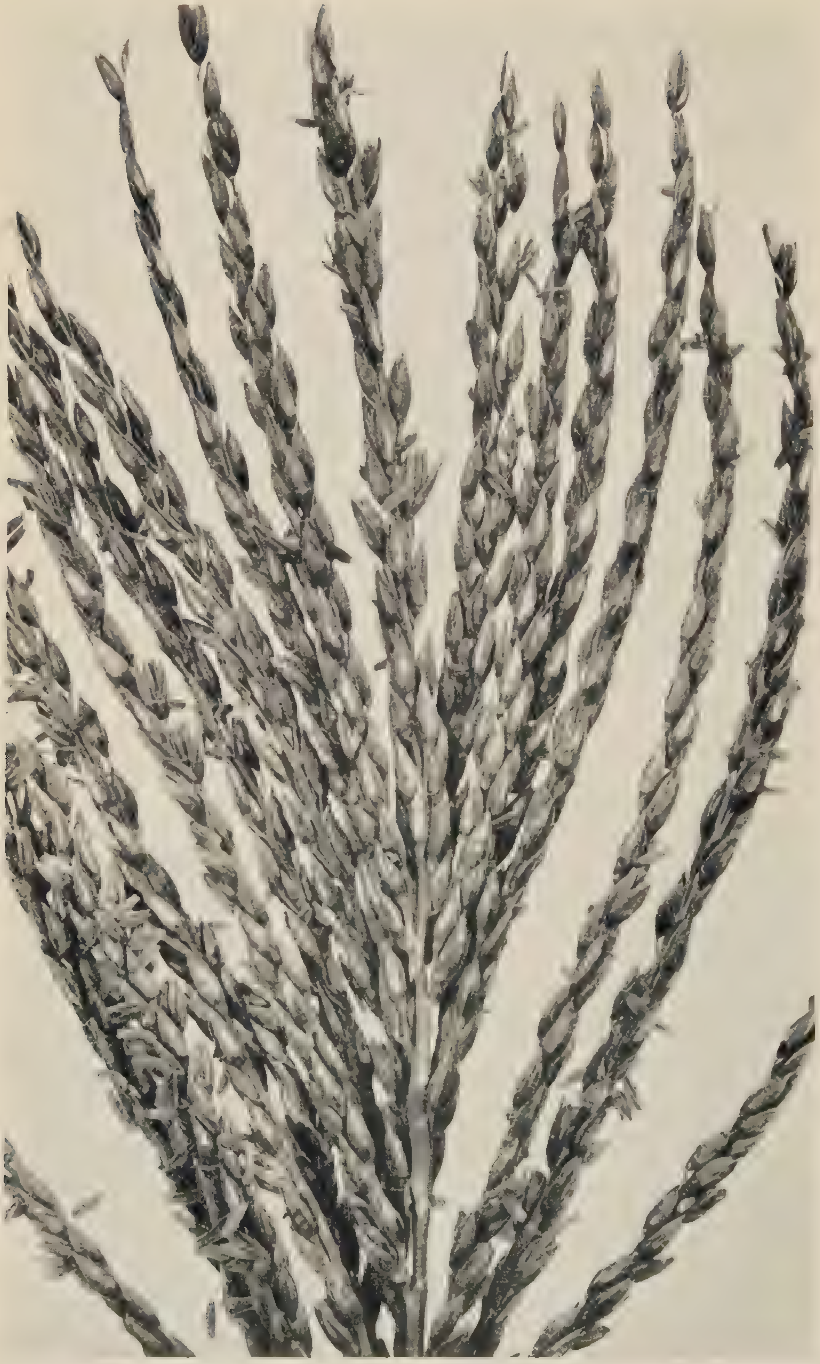


1. A CORN PLANT SHOWING ELONGATED INTERNODES OF THE EAR STALK.



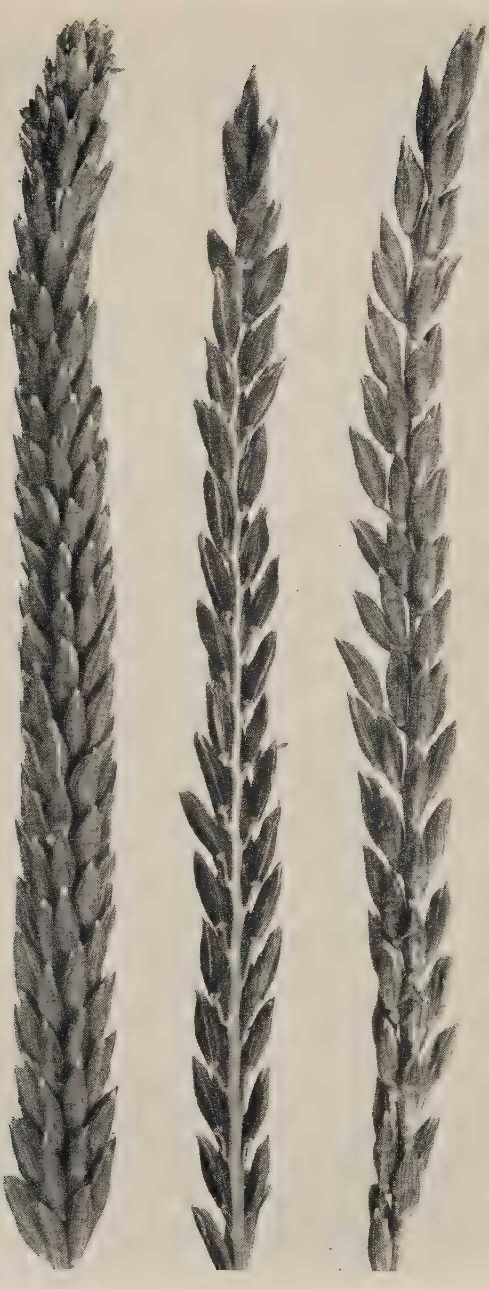
2. A PLANT OF TEOSINTE (EUCHLAENA MEXICANA) GROWING IN CALIFORNIA.

This plant has been arranged to show the production of a branch from the axil of each leaf except the uppermost. Each branch terminates in a tassel, and the seeds are borne in the axils of the leaves of the branches.



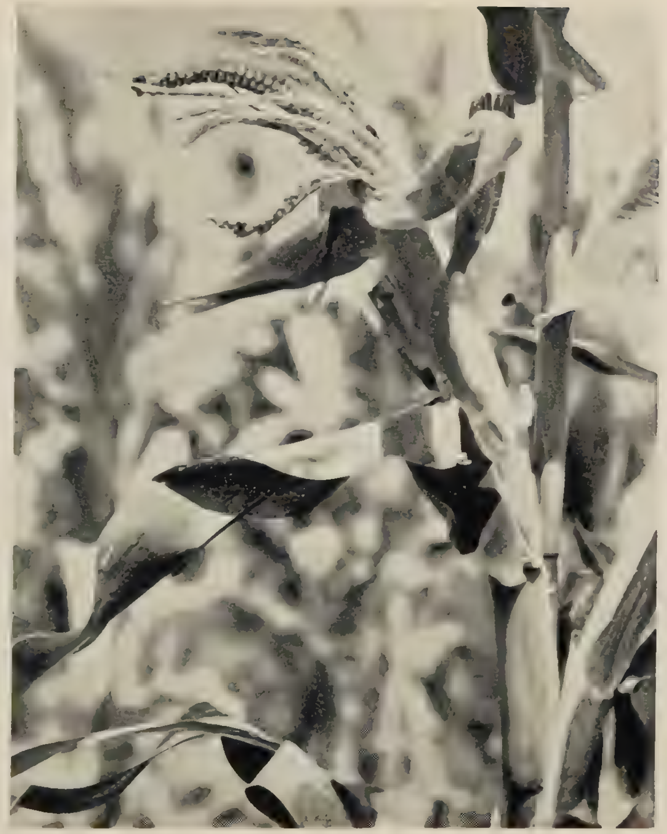
SECTION OF A TASSEL OF TEOSINTE SHOWING THE ABSENCE OF A CENTRAL SPIKE.

The termination of this tassel has but four rows of spikelets as do the lateral branches. (Natural size.)



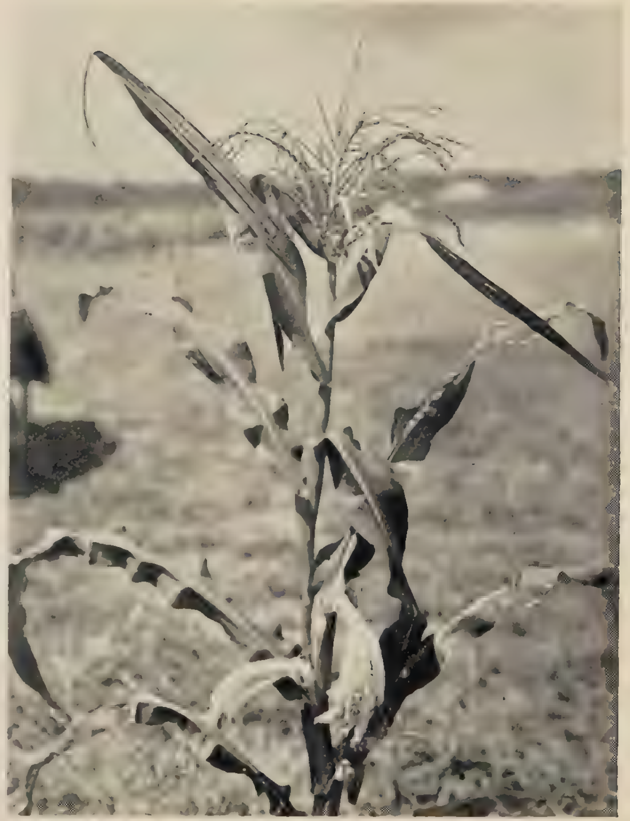
CENTRAL SPIKE AT LEFT AND LATERAL BRANCHES AT RIGHT OF A CORN TASSEL SHOWING THE SPIKELETS IN FOUR ROWS ON THE BRANCHES AND IN EIGHT ROWS ON THE CENTRAL SPIKE.

Dorsal and ventral views of the branches are shown but the central spike is symmetrical. This picture also shows the pairing of pediceled and sessile spikelets. (Natural size.)



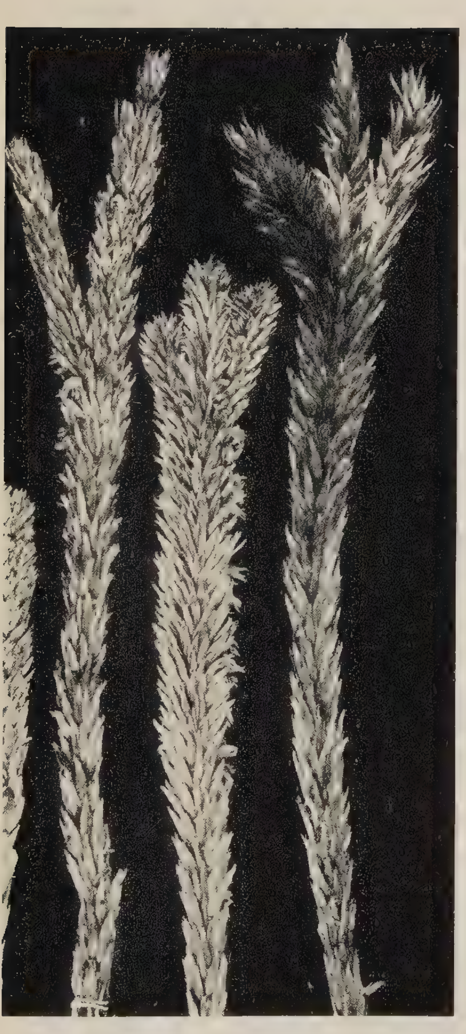
1. AN EAR OF CORN SHOWING A TRANSITIONAL PHASE FROM A BRANCHED PANICLE TO A SINGLE SPIKE.

The central spike of this inflorescence is a well-formed ear bearing only female



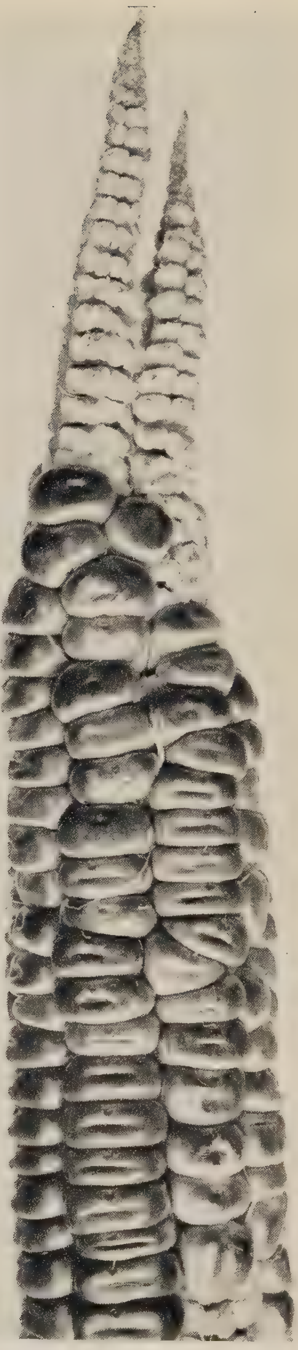
2. BRANCHED EARS.

A form of inflorescence that might be interpreted as primitive since it represents a transition form between the branched male tassel and the single



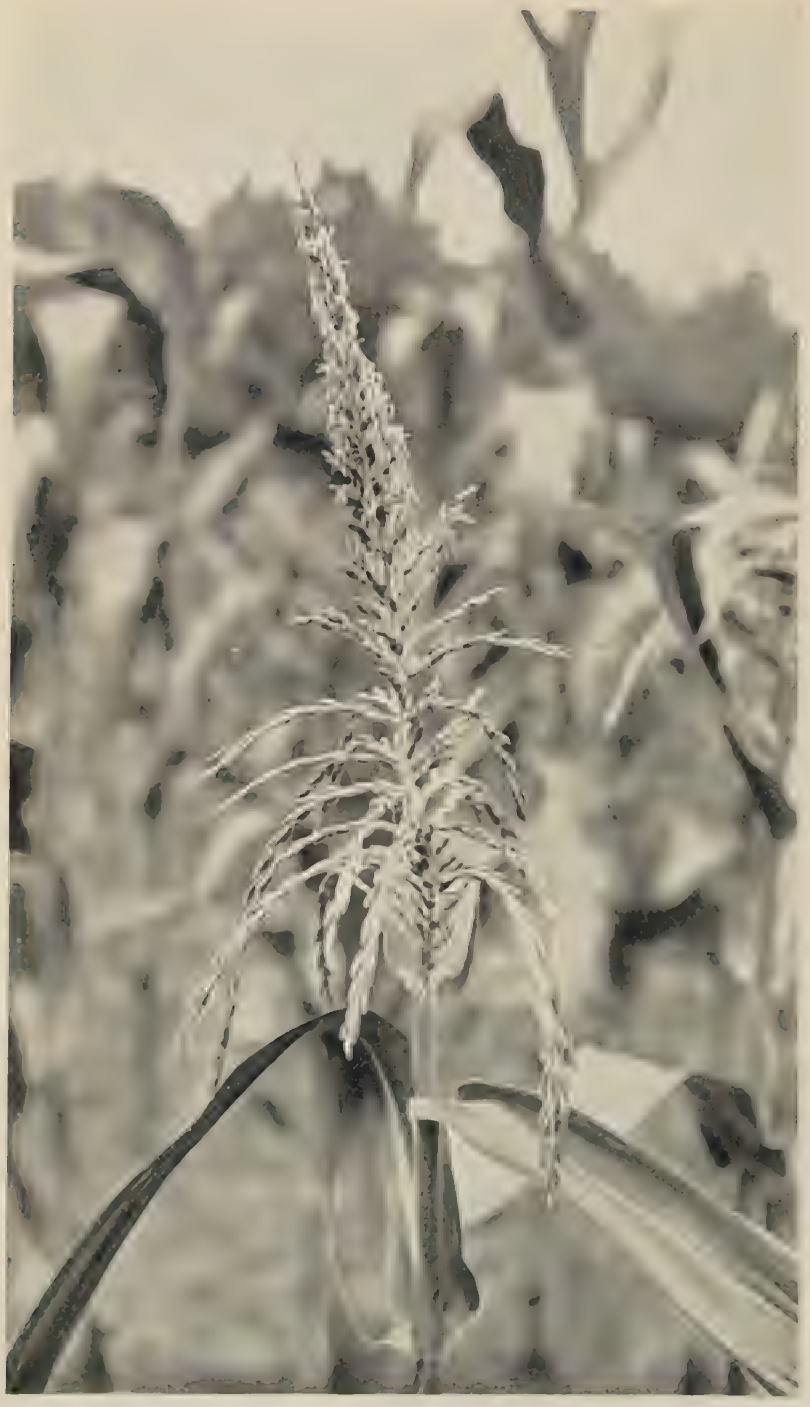
1. FASCIATED CENTRAL SPIKES FROM THREE CORN PLANTS.

Spikes of this sort suggest that multiple rows of spikelets may have come about through the union of 4-rowed branches.

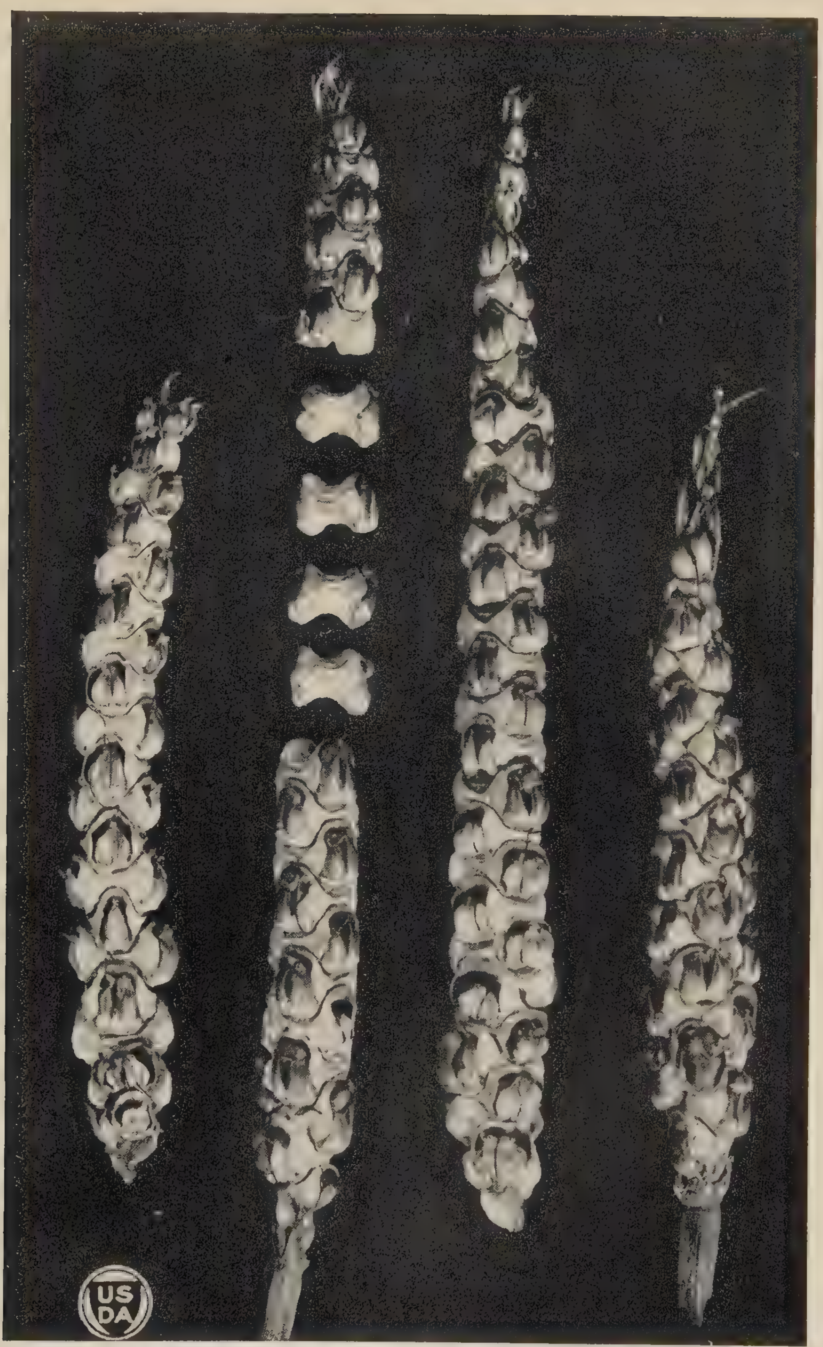


2. AN 8-ROWED EAR OF MAIZE SHOWING BIFURCATION AT TIP INTO TWO 4-ROWED BRANCHES.

Some authorities hold that the ear of maize has been formed by the coalescence of 4-rowed branches. (Natural size.)

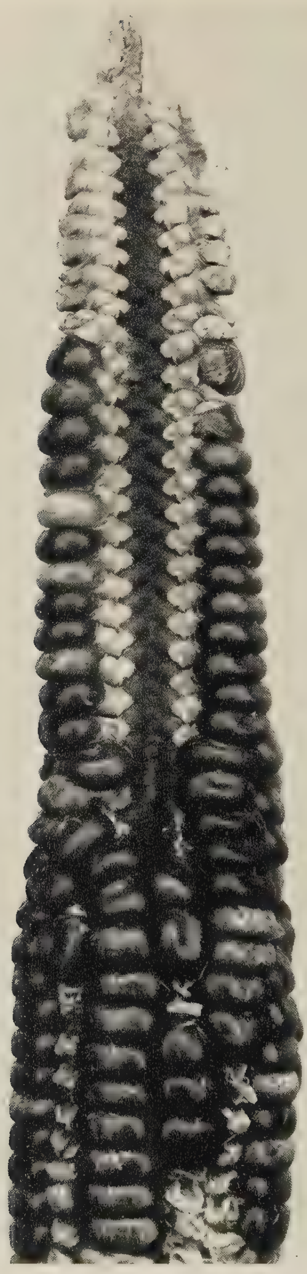


TASSEL FROM THE SECOND GENERATION OF RAMOSE × NORMAL MAIZE, SHOWING THE TRANSITION FROM BRANCHES TO PAIRED SPIKELETS WITH A RESULTING CENTRAL SPIKE.



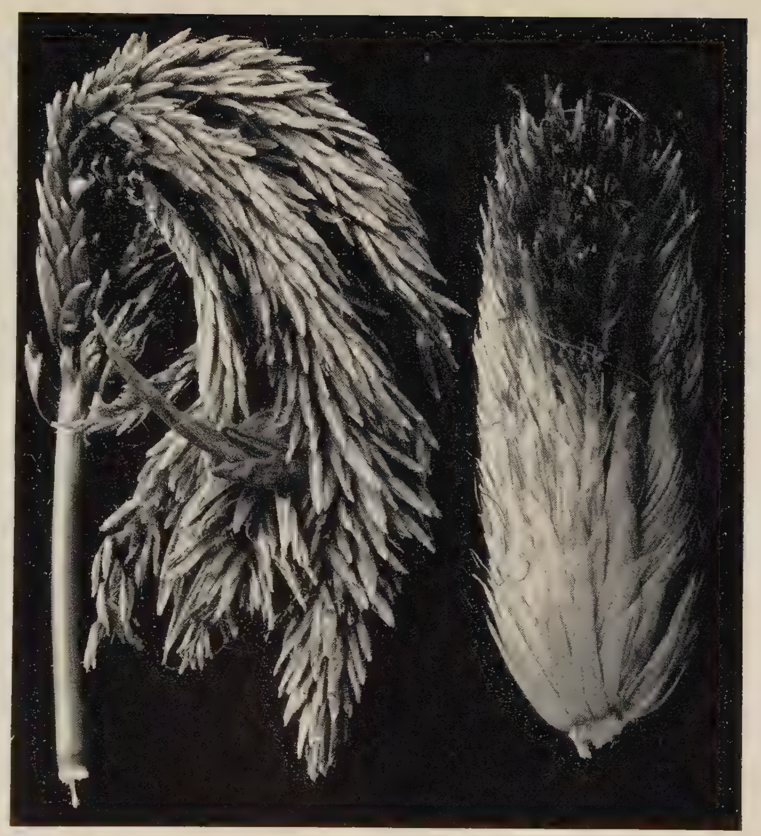
SEED SPIKES FROM THE SECOND GENERATION OF A TEOSINTE × MAIZE HYBRID, SHOWING THE DEVELOPMENT OF AN 8-ROWED EAR BY MEANS OF YOKED SPIKELETS.

(Natural size.)



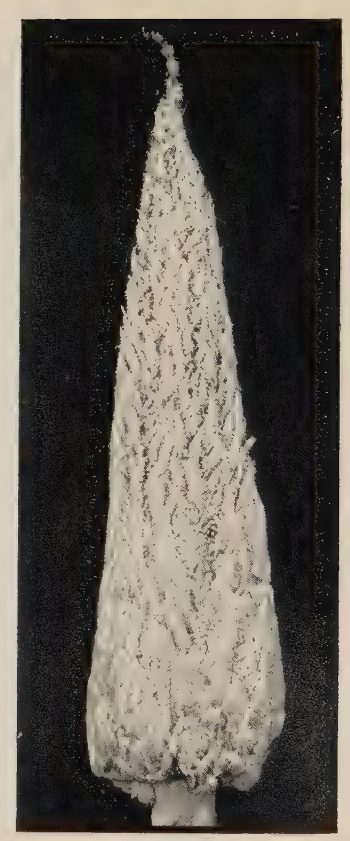
PART OF AN EAR OF CORN WHICH HAS ABORTED FOUR ROWS OF SEEDS (TWO ON EACH SIDE) TO CHANGE FROM AN 8-ROWED TO A 4-ROWED EAR.

(Natural size.)

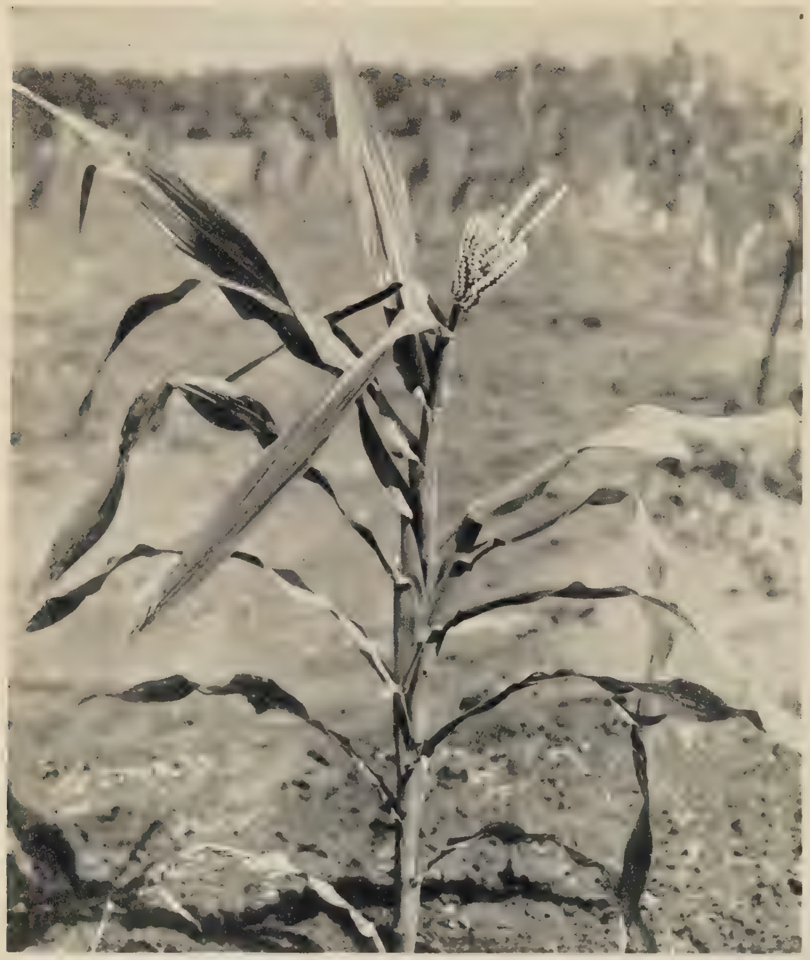


1. EAR AND TASSEL OF POD CORN SHOWING THE LARGE GLUMES THAT ENCLOSED THE SEEDS.

The large object in the tassel, shaped like a rooster's spur, is a spikelet that has been transformed into a branch. Spikelets modified in this manner are common in pod corn.

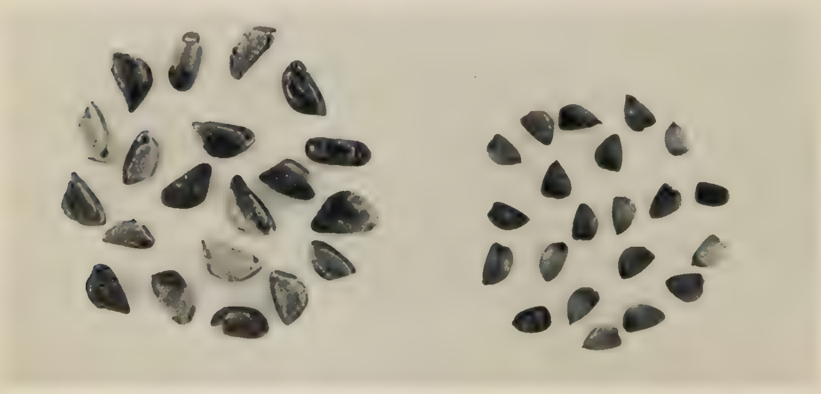


2. "CAULIFLOWER," THE FORM OF STERILE EAR OBTAINED WHEN THE TWO FORMS OF MAIZE, POD AND RAMOSE, ARE COMBINED.



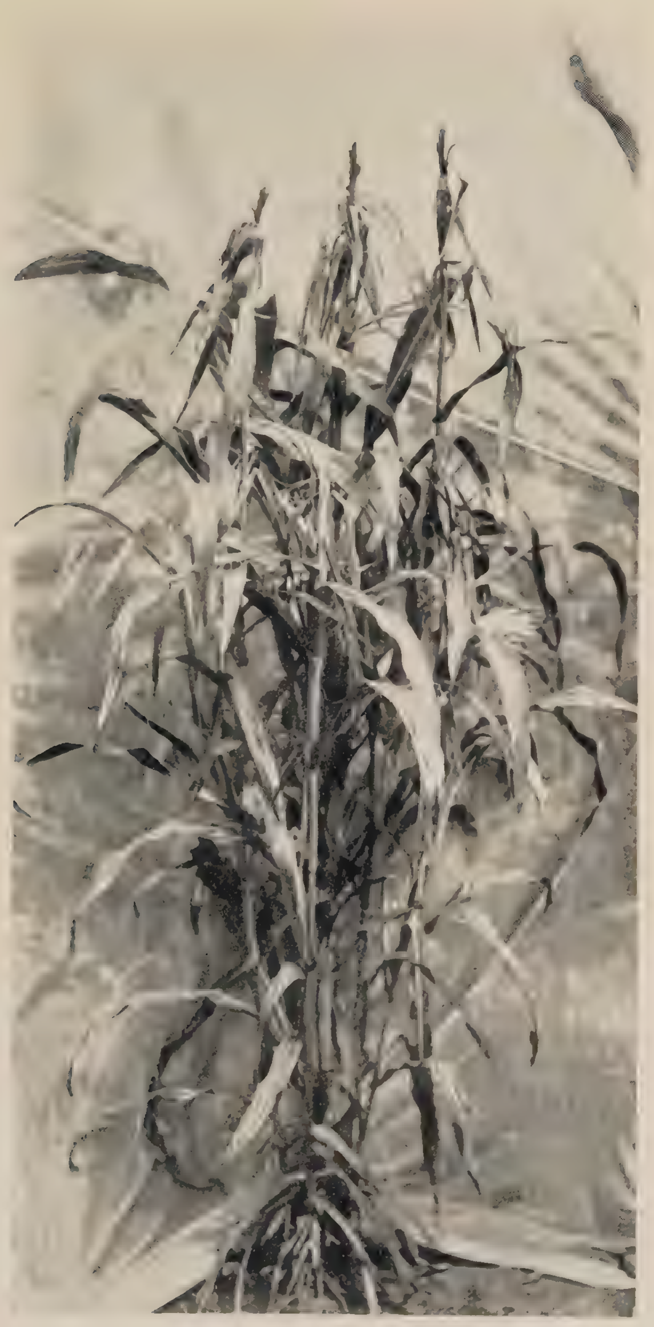
1. TASSEL SEED. ONE OF THE MANY FORMS OF THIS VARIATION IN MAIZE WITH SEEDS BORNE IN THE TASSEL.

This might be regarded as an atavistic return to a primitive form of maize.



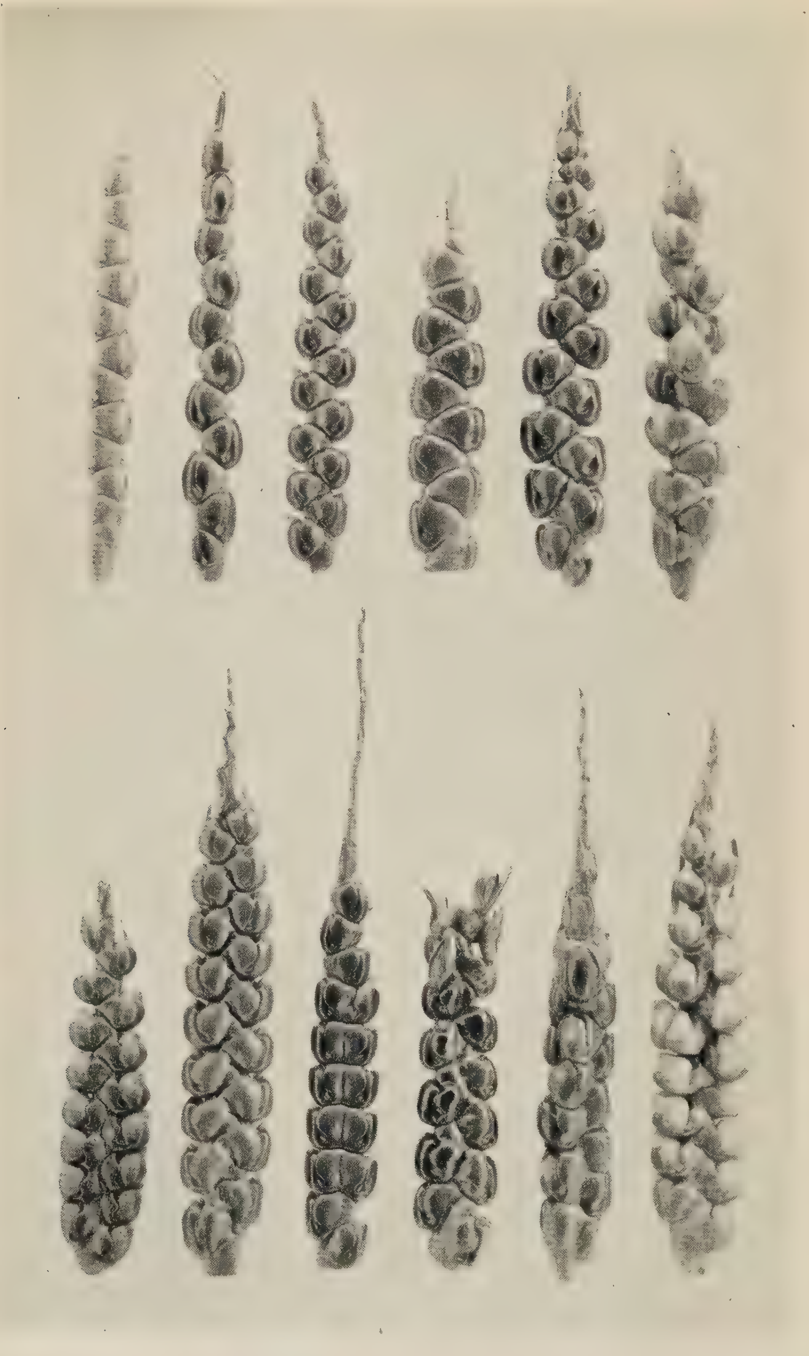
2. AT RIGHT SEEDS OF TEOSINTE REMOVED FROM THE RACHIS SEGMENTS, SHOWN AT LEFT, IN WHICH THEY ARE ENCLOSED.

(Natural size.)



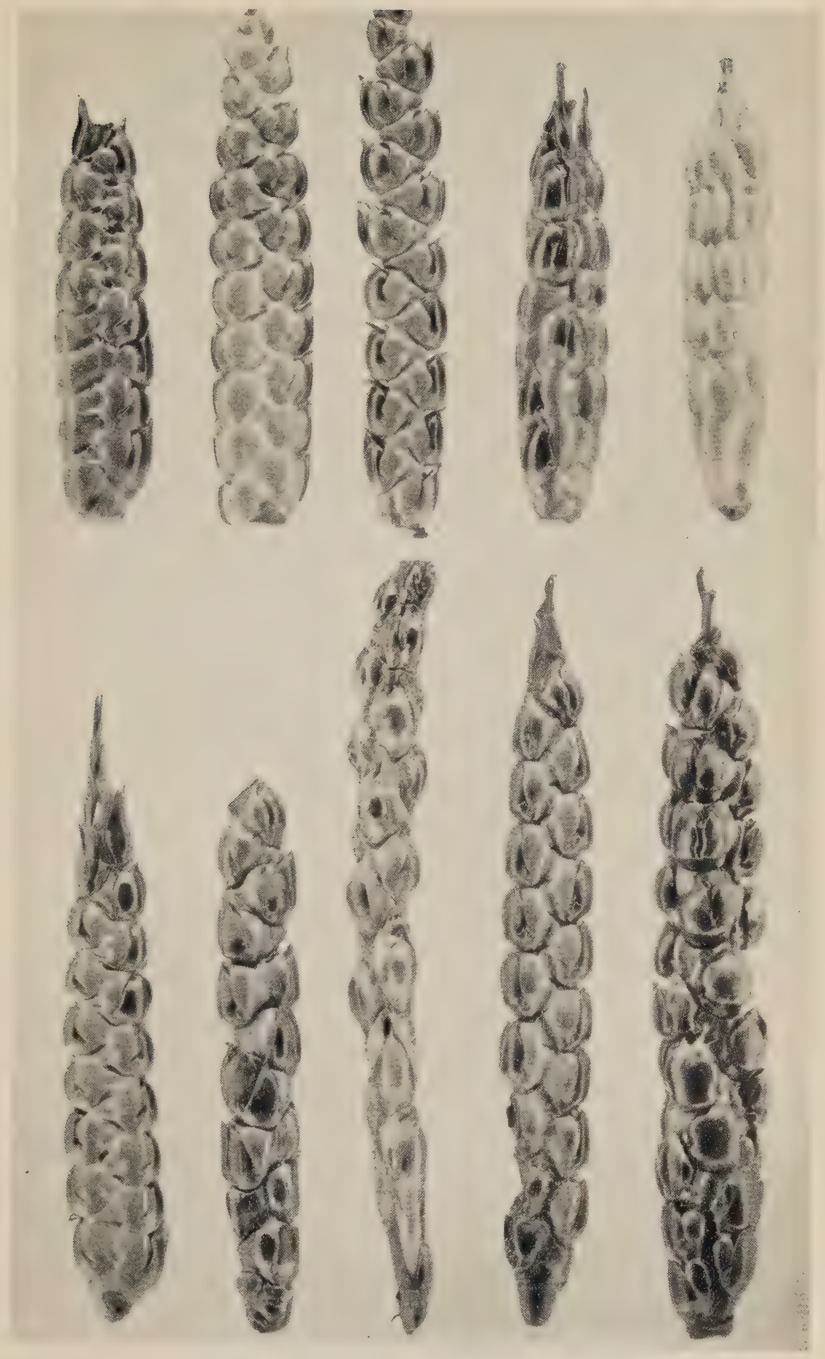
TEOPOD. ONE OF SEVERAL KNOWN MUTATIONS IN MAIZE.

Plants of this mutation differ profoundly in many morphological features from normal corn plants, yet the entire change has resulted primarily from the action of a single gene. The occurrence of such marked alterations as the result of a single mutation lends superficial support to those who advocate that maize may have originated from teosinte by gross mutation.



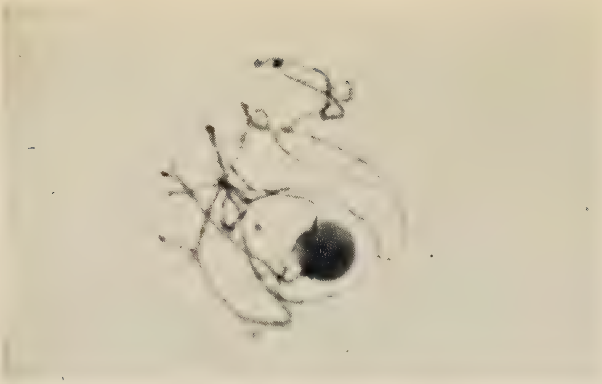
TRANSITION FROM A TEOSINTE SPIKE TO AN EAR OF MAIZE AS SHOWN BY THE SECOND GENERATION OF A HYBRID BETWEEN THESE TWO GRASSES.

Teosintelike spike at upper left. (Natural size.)



CONTINUATION OF THE TRANSITION FROM A TEOSINTE SPIKE TO AN EAR OF MAIZE AS SHOWN BY THE SECOND GENERATION OF A HYBRID BETWEEN THESE TWO GRASSES

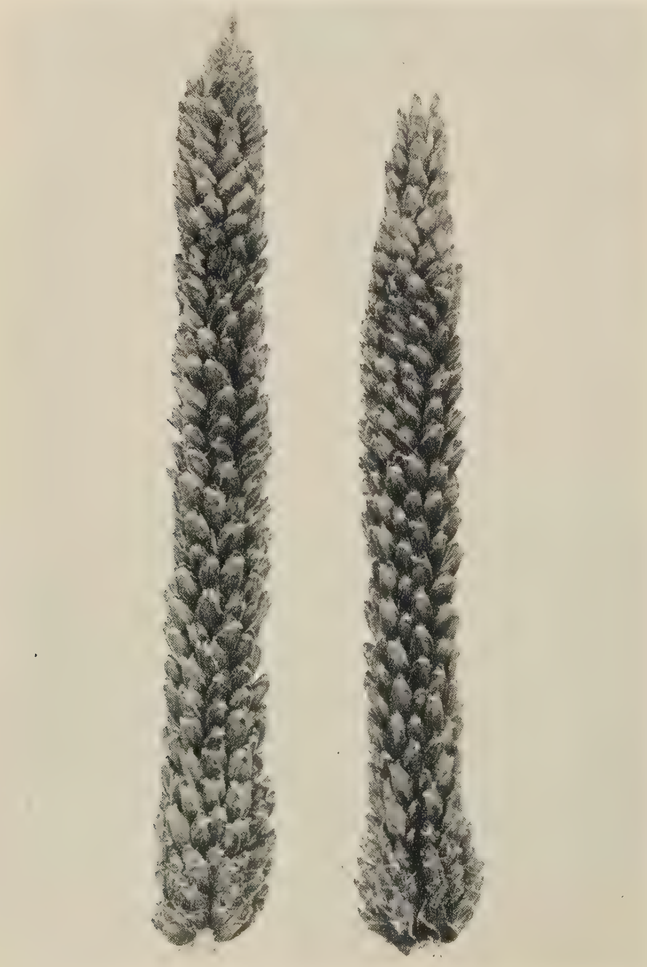
(Natural size.)



A. E. Longley.

1. CHROMOSOMES IN A POLLEN MOTHER CELL OF GUATEMALA TEOSINTE (EUCHLAENA MEXICANA). SHOWING CHROMOSOMES WITH TERMINAL KNOBS

Magnified about 1,000 times.



2. TWO EARS OF MAIZE SHOWING THE FEMALE FLOWERS COMPLETELY SUPPLANTED BY MALE SPIKELETS.

In other forms of maize showing sex aberrations the normally female spikelets become perfect-flowered, each seed being accompanied by three stamens. (Five-sixths natural size.)

THE EMERGENCE OF MODERN MEDICINE FROM ANCIENT FOLKWAYS[1]

By Walter C. Alvarez, M. D.

[With 1 plate]

> In all matters relating to disease, credulity remains a permanent fact, uninfluenced by civilization or education.
>
> Sir Wm. Osler.

Some time ago when I began to arrange the notes for this lecture on the emergence of modern scientific medicine from the folkways of the past, the realization gradually came to me that it hasn't yet quite emerged, and that this fact would have to be taken into account in any discussion of the subject. What I came to see as I looked about me more thoughtfully was that although in its achievements and in its promise for the future, scientific medicine has immeasurably outdistanced the folk medicine, faith healing, cult medicine, and out-and-out quackery which has always competed with it, these competitors, which one would think might now be abandoned as superfluous, still flourish in the land, and still maintain their original hold on the affections of mankind.

As I shall emphasize later on in this lecture, a savage community usually has two types of medical practitioner: One, the witch doctor who cures by incantation and ceremonial and jugglery, and the other, the herb doctor and bone setter, who, according to his lights, practices much as does a scientific physician. Among the savages the witch doctor is usually held in higher esteem than is the herb doctor, and so also in the supposedly civilized parts of the world the quack often pulls in the crowds and waxes rich while the less spectacular but well-trained physician plods on without much acclaim.

For instance, a few years ago in the environs of Paris, crowds flocked to the booth of a man who was selling herbs to the accompaniment of an attractive and plausible line of patter. When the police arrested him for practicing medicine without a license, they discovered to their surprise that he was not a quack but really a licensed physician, and they were still more surprised when he begged them not to reveal this fact. As he said, if his customers were ever to hear that he was an educated physician they would all leave him, and he would have to go back to poverty.

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[1] Read at the open meeting of the Minnesota Chapter, Jan. 24, 1936. Reprinted by permission, with some alterations by the author, from the Sigma Xi Quarterly, vol. 24, No. 3, September 1936.

MANY PERSONS VOTE FOR QUACKERY

In States which use the initiative and the referendum, the people commonly vote down laws designed to debar ignoramuses from the practice of medicine, and sometimes they will go even further. Thus, in a certain city of this land, when a wealthy man presented the citizens with a much-needed hospital, they accepted the gift with the donor's proviso that the place be maintained always as a class A institution, that is, one in which only reputable and licensed physicians are allowed to see patients. But soon the few back-manipulators in town were protesting volubly that as taxpayers they had a right to practice in the city hospital, and so the people went to the polls again and voted to break their covenant with the donor and to turn the building over to the back-rubbers. Hence, when last I had news of the situation, the regular physicians were out, and the town was back where it was before, without a satisfactory hospital.

Actually, the presence of this large group of people in some communities, unappreciative of, or militantly hostile to, scientific medicine makes it impossible for health officers to stamp out diseases such as smallpox and diphtheria, against which, for years, science has offered adequate means of protection.

MANY GO TO IRREGULAR PRACTITIONERS BECAUSE REGULAR MEDICINE FAILED TO HELP

Now I know that there are several reasons for the great faith many people have in irregular practice by poorly trained and inexperienced men. I hate to spend time now in talking about these reasons but I fear that if I do not explain why I am not impressed with the cures worked by irregular practitioners and why I do not favor the licensure of such men as physicians, some of you will think me hopelessly biased and intolerant. I feel myself somewhat in the position of an astronomer invited here to describe the emergence of modern astronomy from ancient astrology. Knowing that many of you believe in astrology, he would not dare to speak disparagingly of it without going on to explain why he thought it a form of quackery which should have been left behind in the dark ages. He would feel all the more like giving this explanation if the present-day belief in astrology were hampering the development of astronomy in the great observatories of the world, much as the widespread faith in quackery is now blocking the efforts of health officers to eradicate disease.

Perhaps the main reason why quackery thrives today is that there are still so many diseases which the scientific physician cannot cure. I feel confident that eventually many of these will be conquered, but I doubt if my profession will ever be able to make over those millions of poor, broken-down men and women who either inherited bodies and nerves too frail to stand up to the strain of life or else had burdens laid on them heavier than they could bear. These people throng our offices every day begging for help, but in so many cases "the contractor put in poor materials," and the only way in which one could hope to work a cure would be to begin with a different set of grandparents.

Nor can the physician yet replace defective or worn-out parts, or parts already destroyed by disease, when the patient comes for help. When a fire in a big conduit burns out some wires, and part of a town is left in darkness, down the manholes go the linemen and soon new wires are strung. But when the poison of infantile paralysis has eaten a hole through the cable of nerves supplying the leg muscles of a little boy or girl, there is no way in which the neurologist can get in and repair the damage, and no one who knows what has happened would think of promising the poor, worried parents a complete cure. Much that is helpful can be done by an expert orthopedist, but he cannot put back the injured nerve cells.

Similarly, the physician cannot take out grandmother's creaky knees and say, like an automobile repair man might do: "See, there, the rubber cushions and the oiling system are practically gone, and the surface of the bone is burred over from much pounding, just as in the case of an old chisel. You'd better let us get you a new pair of joints from the factory!"

Some day surgeons may be replacing such parts, because already they have developed the necessary techniques. The only reason why they are not doing it now is that as yet research workers have not learned how to keep the transplanted parts from being digested away by the blood of the recipient. But Dr. Stone has made a hopeful start toward overcoming this difficulty, and eventually we may be putting new kidneys into the patient with Bright's disease, and perhaps even a new heart into the man whose cardiac arteries have begun to plug up with scar tissue.

In the meantime, the huge army of the weak, the unfit, the psychopathic, the crippled, and the ailing will ever be on the lookout for a worker of miracles. And one cannot blame them: They are desperate and ready to try anything once. They and their loved ones will always be scanning the horizon for hope, and they will always be ready to spend the last penny of their savings on a journey to the home of some new wonderworker.

WHY QUACKS OFTEN APPEAR TO WORK MIRACLES

But some of you will remind me that sometimes the quack does cure after able physicians have failed. And you are right; I have seen this myself, but no one who knows anything of quackery, or human suggestibility, or hysteria, or the tendency of most diseases to let up without any treatment at all, is ever going to conclude that simply because a man is curing some people and is gathering crowds on his doorstep he is a good physician, and his system of practice is worth investigating or imitating. This statement will doubtless seem so paradoxical to some of you that probably I should digress for a moment and explain.

PATIENTS WHO CANNOT AFFORD TO GET WELL TOO QUICKLY

Occasionally I see patients who I feel sure could be cured more easily by some spectacular form of quackery than by my prosaic brand of psychotherapy. For instance: During the World War a young man's business necessitated his traveling back and forth through an ocean infested with German submarines. He went without protest, outwardly brave, but inwardly terrified. One day in Europe everything went black, and he returned home stone blind.

From the minute when I first saw him I felt that the blindness must be hysterical in nature. A man can hardly associate with the sick day after day for 30 years without learning the significance of many a little telltale sign, and as I expected, when I told him I thought he could be cured he showed no enthusiasm and soon departed.

Later, as I thought the problem over, I saw that I couldn't hope to cure him with undisguised psychotherapy because if I did, this would leave him in an embarrassing situation. It would expose him to the accusation of having been either a fool or a coward or a cheat. No; he could afford to get well only in some spectacular way, and I was not at all surprised some months later, when I saw by the papers that an irregular practitioner had reduced a dislocated vertebra in the neck, a vertebra that had been pressing, so they said, on the optic nerves. As you know, these nerves do not go anywhere near the neck, but no matter—the fact appears to have been that the patient's sight was instantly restored.

Now imagine the effect of such a newspaper report on the minds of blind men and women everywhere; they who have gone to many oculists without help and without encouragement. It will immediately occur to some of them that perhaps they, too, have a displaced vertebra, and it certainly wouldn't hurt to look. And so they borrow what money they can or draw out their little savings, and off they go to see the new miracle man. The sad thing is that in 99 such cases out of 100 the eyes are hopelessly damaged, and the poor blind man must return home even more discouraged than he was before.

STRIKING PERSONALITIES THAT HEAL

Often the cure, when it does come from an irregular practitioner, is worked not so much by the massage or the manipulation as by the influence of an unusual and commanding personality. A few months ago while lunching at a club I couldn't take my eyes off a big, tall, striking-looking man, with piercing black eyes, long black hair shot with gray, and a strangely moving, deep and musical voice. I said to the friends with me, "What a wonderful quack he would make", and then they told me that actually he was a sort of faith healer. He was a preacher who, having discovered one day that he had the gift of healing by the laying on of hands, had gone over into the practice of medicine.

Actually, all great physicians seem to possess some of this ability to inspire sick persons with confidence and hope, and to lift them up out of a bog of worry and fatiguing thoughts and onto the road to health.

CURES DO NOT JUSTIFY A QUACK

As I have already said, the fact that a healer is besieged by hordes of patients, many of whom depart singing his praises, does not indicate for a moment that his methods are rational or worth using by other men. In the hands of the next man they may fail utterly, and for that matter, they usually fail after a time even in the hands of the original user. For this reason nearly all forms of quackery have their day, and then they lose ground and disappear.

Perkins' tractors.—Thus, toward the close of the eighteenth century, Elisha Perkins, an American physician, was curing disease right and left with two little, supposedly magnetic, pieces of metal called tractors. He did so well that even George Washington got a pair. After Elisha died, his son took the tractors to England, where he made a great stir and enlisted the support of the nobility. Unfortunately for him, the famous Dr. Haygarth was skeptical. First he held clinics at which he demonstrated how patients lost their pains when the affected parts were stroked with the tractors. Then, when everyone was much impressed, he took out his penknife and cut the supposed magnets in two; they were imitations made of wood. In the reaction that followed, educated England laughed, and Perkins left for home.

Asuero.—In Madrid, a few years ago, an unimportant physician named Asuero announced that all diseases were due to trouble in a little nerve in the nose, and easily curable by local treatments. The idea caught on, and soon there was a line of people on the sidewalk each morning waiting to get into his office. As commonly happens with quacks, the wealthy and the aristocratic made much of him, and in 2 or 3 years he accumulated a large fortune.

Then, apparently, he ran out of suckers, and with nothing to do, he left for Italy to see if he could start there all over again. But the Italians did not take to the idea, and when last I heard of the man he had failed to get going even with the help of his old prestige, his wealth, and the support of some dukes and duchesses. His imitators also failed. Some of you may ask: But didn't the method have some value? Yes; it was nothing new. Nose specialists have used it for years, and with it have helped occasional patients with hay fever and headache.

Albert Abrams.—Another typical story is that of Albert Abrams, a licensed physician of no great reputation in California. For years he promoted a scheme for curing disease by pounding the spine with a little rubber hammer. But the idea never took hold, and until he was about 60, Abrams had only a mediocre practice. Then one day as he sat looking at one of the first little radio sets, he got an idea that was soon to bring him in a million dollars. He took a couple of cheap resistance boxes and an old Ford spark coil, hooked them together in the silliest way, and announced to the world that with this magic detector he could tune in on the electronic vibrations coming from a drop of blood and could tell exactly what disease the patient was suffering with. For good measure he would tell if the sample of blood came from a Chinese or a Jew, or from a Presbyterian or a Catholic! Just as easily he could connect the patient to another silly box of wires and tune the disease right out of him.

To people who were just beginning to realize what marvels the radio tube could perform, this all sounded so reasonable and so up to date that thousands flocked to him and paid $100 or more to sit for a while holding onto the end of a wire out of which was flowing—absolutely nothing. Many felt that they were cured, and writers like Upton Sinclair, who swallowed hook, line and sinker, wrote articles accusing the leaders of the medical profession of narrowness, backwardness, and jealousy, and an inability to recognize genius when they saw it. The fact that Professor Millikan, on the witness stand in a malpractice suit, swore that he had examined the instruments and that they couldn't possibly do what they were supposed to do, did not seem to discourage anyone.

And then Abrams died, and without his frequent startling pronouncements, which had served to keep his name in the newspapers, his disciples found themselves with but few patients, and most of them were compelled to shift over into some other better advertised and more popular form of quackery.

SELF-LIMITED DISEASES

But some of you may still be saying that you know of a man who was lying at death's door and, after treatment by some irregular practitioner, got well. Yes, this happens all the time and yet it usually proves nothing. Many is the time that I have received great credit for cures which I know good old Mother Nature had more to do with than I. I can remember one of the lucky breaks that came to me when I was a young man starting out in the practice of medicine. A man lay ill with pneumonia and, as usually happens in this disease, each morning of the first week found him worse. Not knowing enough about the disease to expect this, the wife became convinced that the nice old doctor in attendance did not know his business and dismissed him. I was then called and I barely had time to change the medicines before the crisis came—and my reputation was made! I tried to explain to the people that they must not blame the old doctor because in this case the pneumonia had run a very typical course to recovery, but they thought I was just trying to be modest; and so finally I gave in, and said no more, salving my conscience with the conviction that sooner or later I would get my share of disgrace perhaps as undeserved as was my present credit. And so it happened; my next patient with pneumonia did so badly that I was dismissed; the old doctor was called in shortly before the crisis came, and thus he got even with me.

Now, you may smile at all this, but just remember that such things commonly happen when next you hear of a case like the one I will now describe. A nationally known educator lay ill with pneumonia. The ninth day came and no crisis; and, because the physicians in attendance looked anxious and shook their heads ominously, the family discharged them and called in a back-adjuster who only a short time before had been a bathhouse attendant. Next day the crisis came and, for the rest of his life, that distinguished college professor—who should have known better—extolled to his friends the virtues of a certain cult and the skill of a certain ignorant but pleasant and well-meaning man.

Curing a disease that wasn't there.—Or here is the fairly common story of another type of case in which the irregular practitioner triumphs because either he or some good physician diagnosed wrongly. The case is that of a very wealthy woman who was operated on years ago for a tumor of the large bowel. It looked so much like an inoperable cancer that the famous surgeon in attendance did not attempt to remove it, but simply made a bypass around it. Later, as more experience came to him, he realized that what he had seen was not a cancer at all but only an inflammatory mass that would probably disappear after the type of operation that he had performed. But in the meantime, the patient had gone to a faith healer; and when years passed and she remained well, she built for this healer and her faith a beautiful church. Always, then, when one hears that some healer has cured a cancer, it is well to remember the possibility that the diagnosis was wrong.

Cures that won't work twice.—And here is yet another type of case. Recently I saw a woman with severe arthritis. She told me that 5 years before, when the disease first flared up and put her in a wheel chair, she went to a quack who cured her with the help of an herb tea. Naturally, I asked her why she wasn't back taking the same treatment again, and her answer was that she had gone but that this time the tea wouldn't work. The chances are, then, that the first spectacular cure was not a cure at all but only one of those spontaneous remissions which are so common in the course of a lifelong disease.

THE DIFFICULTIES INVOLVED IN JUDGING OF THE VALUE OF A TREATMENT

The average layman has no conception of the pitfalls which lie in the path of the man who would appraise the value of some particular treatment, especially for a self-limited disease. For instance, last October some of you doubtless took "cold shots" to protect you through the winter. If when summer comes you are still without a cold, will that prove that the vaccine was helpful? Not at all; you may be delighted with what seems to you a miracle, but I can assure you that the reports of dozens of such successful cases mean nothing to the medical statistician. The only way in which to learn anything definite about such a treatment is to do as the Metropolitan Life Insurance Co. did several years ago. They took, as I remember, some 5,000 of their employees and vaccinated half of them, leaving the other half to serve as what we physicians call a "control series." At the end of the year they checked up and found that the 2,500 who had been vaccinated had had just as many colds as did those who weren't vaccinated; the only difference was in the severity of the colds, the vaccinated men and women getting back to work on the average several days sooner than the others did.

Sometime ago, Dr. Diehl, of the University of Minnesota, made a splendid study of colds among the students, trying out on hundreds of them several of the drugs that are commonly used in this disease. He found to his surprise that one out of every three colds cleared up in a day or two without any treatment at all, and others cleared up so rapidly or ran so mild a course that it was impossible to say whether or not the remedy given had anything to do with the prompt recovery.

No wonder, then, that practically everyone thinks he can cure a cold. Hasn't he cured many of them with his pet method? To be sure, some of the colds treated hung on stubbornly, but following the convenient rule of humankind, he forgot these and remembered only those which he "cured." And if he, who has had no training in medicine, can have had such splendid success in his little practice, why should anyone have difficulty in believing that other uneducated persons can cure disease, especially when they have inherited some special skill or some secret formulas for powerful remedies? So why should there be all this demand that physicians be educated men?

Actually, it is only the highly educated physician who finds it difficult to take seriously the pretensions of healers who have spent only a year or two in a low-grade college; he alone knows how hard it is to practice good medicine even after half a lifetime spent in study.

BELIEF IN THE MIRACULOUS INCULCATED IN EARLY LIFE

But there are yet other reasons, and very strong ones too, why all of us look for miracles when it comes to the treatment of disease. We may have spent 4 years at college learning that the universe is run according to immutable laws, but throughout our youth, and almost from the moment that we could understand speech, we were taught to believe stories of miraculous suspensions of these laws, and we were urged to ask daily that such miracles of protection be performed for us and for our loved ones.

Furthermore, in our daily contacts with the people about us and with the world of books, we absorb, willy nilly and unconsciously, much medical folklore which inevitably has an influence on our thinking and our behavior. And if it influences the behavior of an educated man, how much more must it dominate the thought and the behavior of the ignorant and the naturally credulous? None of us can escape it. You sneeze, and some old person near you says, "God bless you." Why did she do that? She probably does not know, but her ancestors in Europe could have told us that you sneezed because a little devil was just then entering your body with evil intent, and when your friend called upon the name of God, that devil had to get out in a hurry. Unconsciously, you subscribe to the same idea when you say, "I wonder what possessed me to do that?" or "I wonder what can have gotten into that child."

Or let us suppose that, without thinking in time to stop myself, I remark to my wife that it is almost a year since I had a cold. I immediately rap wood, but why? Actually, on looking this up in my library on folklore, I found that I do not do it right. I really should be pounding so hard on a log and making so much noise while I am bragging that the devil will not be able to hear me and to say, "Watch me and see how I take that cocky fellow down a peg." Now isn't that silly, and yet I keep on rapping wood on every appropriate occasion, just because it makes me feel safer.

But you can't laugh at me because you have your own pet superstitions. Perhaps you have a horseshoe over the barn door to keep out the elves that would ride the horses all night and sicken the cows and poison the churn. Or let us suppose that you start to pick a sliver out of your finger with a pin and your grandmother catches you at it. You know that she will insist that you use a needle. But why? For 20 years I have been asking grandmothers that question. They all agree that one must use iron and not brass, but the two lame explanations which they give can easily be shown to be inadequate. I searched for years through the literature on folklore for information on this point until at last I became convinced that the original reason was that if iron is used it will keep the wicked elves away from the wound just as iron over the door will keep them out of the house.

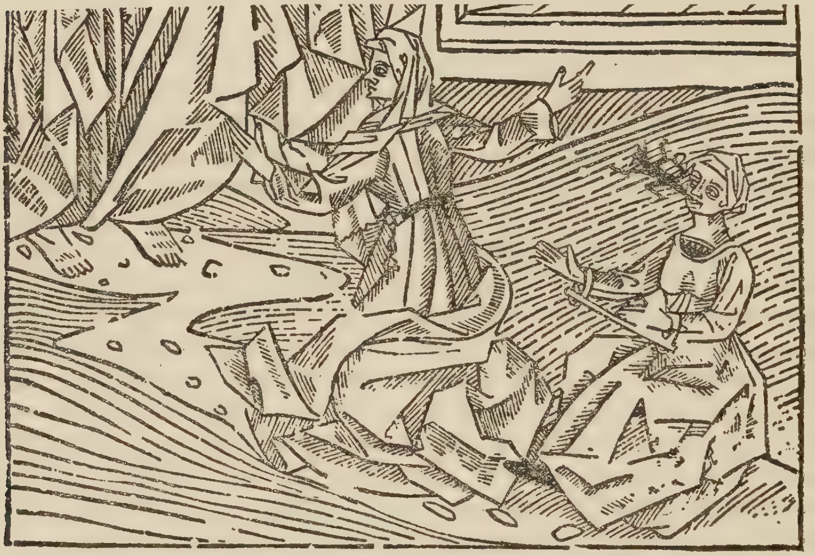

FIGURE 1.—Christ, whose feet are seen at the left, is casting the devil out of the insane daughter of a poor widow. This illustration from the Biblica Pauporum shows how, as late as the fifteenth century, people firmly believed that evils took possession of people and could be cast out bodily as shown in this illustration.

When you use a brass pin you have no protection, and the wound may fester.

But some of you may ask: Why should the iron protect? Briefly, it is because the elves and the old gods and demons were very conservative; so much so that for thousands of years they clung to the use of the old chipped flint axes and knives of our cave-dwelling ancestors. Eventually they got so that they could tolerate bronze, but even yet they cannot abide nor even go near the newfangled iron which came into use about 1000 B. C.

Or, let us suppose that today, as a young mother sits trimming for the first time her baby's nails, the grandmother comes in. Why will she be so upset and why will she perhaps get down on the rug and pick up all the little parings so as to destroy them in the fire? Why will she say that for the first year of the baby's life the nails must be bitten off? Ask her and she will probably say that if this is not done the baby will grow up to be a thief or it will sicken and die. But let us ask the official nail-paring swallower of a Madagascar chief (I have read in scientific treatises that there is such a man) or let us ask any savage anywhere on the face of the earth, and he will tell us that when the nails are bitten off the pieces must be swallowed. If they were to be left around, and a bad witch were to get hold of a piece, she could easily say some spells over it, and disaster would soon come to the baby.

I never cease marveling at the antiquity and the wide dissemination of scores of these beliefs. For instance, there are many poor homes in England today in which, if a child is seriously ill, the grandmother will want to administer a skinned mouse as a medicine. But why a mouse? To find out we have to go to Egypt where each year as the Nile subsides and the peasants go back to their fields, they find in the cracks in the mud an abundance of mice. They think that these mice sprang from the mud, and therefore must represent an essence of the life-giving virtues of the river. What is more appropriate, then, than to save a dying child with a medicine which represents life abundant? And now comes what, to my mind, is the most interesting part of the story, and this is that when Elliott Smith was studying the mummies of some little children who lived in Egypt over 6,000 years ago, long before the pyramids were built, he found in each stomach—a mouse!

ANCIENT THEORIES OF THE CAUSATION OF DISEASE

Now it will be noticed in the examples which I have given of present-day medical superstition that disease is usually supposed to be due to the malevolence of the devil or of witches or wicked elves, or of men who know enough of the magic arts to summon help from the powers of darkness. What is more natural, then, than to assume that health is to be maintained by warding off evil in some magic or symbolic way.

But where did we get these ideas? I feel sure that we got them from our remote beetling-browed ancestors who hunted the reindeer and the woolly mammoth in the days when the great ice sheets were retreating northward toward the pole. But someone says: How can anyone know what those ancient savages thought? Well, we cannot know for certain, but here and there in the few remaining wildernesses, explorers come upon men who live in a stone age very similar to that of our ancient ancestors, and always these men are found to have about the same ideas in regard to disease. Never having heard of germs or high blood-pressure or hardening of the arteries, it never occurs to them that a man might die of natural causes. If he wasn't injured in an accident or mauled by an enemy or a wild beast, then he must have been harmed by witchcraft or he must have offended some deity or broken some tabu.

One of these ideas has come down to us embalmed in a word. Thus, when an old man drops to the floor unable to speak or to use his right arm or leg, we physicians say that a blood-vessel in the brain has either ruptured or been plugged in some way. But the layman says that it is a stroke, which implies that God was angry and reached out and struck the man down. I never realized how fully a college graduate could believe this until one day when, as I sat by the minister's wife, encouraging her to learn to talk again after a bad cerebral thrombosis, I found that the endlessly recurring question in her mind was: "Wherein have I sinned so terribly that God has struck me down in this cruel way; why has He done this to me who have served Him lovingly all my days?"

But to get back to the savages and their ideas of medicine: Seeing that to them disease is due purely to the malevolence of gods and witches, it is easy to understand why their most prized physicians are not expected to have any knowledge of the body or of surgery or of healing herbs; all they are asked to do is to find out which god is angry and why, or which witch is at work and who is employing him. After that they must know how to appease the god, or to nullify the evil charms of the witch with yet stronger charms and spells.

THE TWO TYPES OF HEALER AND THEIR DESCENDANTS

And so it is that wherever on this earth one encounters primitive people one is likely to find that the most respected and most feared man in the tribe is the witch doctor. Often he is a sort of Pooh Bah who exercises the functions of physician, seer, prophet, priest, sorcerer, master of ceremonies, and perhaps even king. Sometimes he represents the finest flower of the development of his people, and then again he may be little more than a juggler and an assassin who will kill for a price.

But what happens when a savage falls out of a tree and breaks his legs, or comes back from a raid with part of his scalp hanging over his ear, or what is done to help the man who gets constipated or has a boil that needs lancing? Will the witch doctor bother with such small practice? No, that is usually beneath his notice, and hence in every tribe there is another kind of healer, a man or woman who can clean wounds and bring the edges together, who can splint a broken leg or pull a dislocated bone back into place, who can incise an abscess or knock out an aching tooth, who can massage stiff muscles or give a sweat bath, and who knows the lore of medicinal plants.

And here I get to the central theme of my discourse, and this is that from the time when man first stepped down out of the trees and made himself a stone ax down to the present moment, there have always been, in every community, two types of medical practitioner: One a believer in some supernatural or similarly unprovable and ready-made explanation of disease as a whole; the other, a student of the many diseases as he finds them; the one disdainful of the study of the structures and workings of the human body; the other a deep student of these sciences; the one treating by means of charms and spells, ceremony, hocus pocus, exorcism, and sacrifice; the other treating with physical and chemical measures; one whose forte is the cure of nervous troubles, hysteria, and self-limited diseases; the other whose greatest success is found in the healing of those lesions such as deep wounds or bad fractures in which Mother Nature, unaided, either fails to cure or else ends up with a bad result.

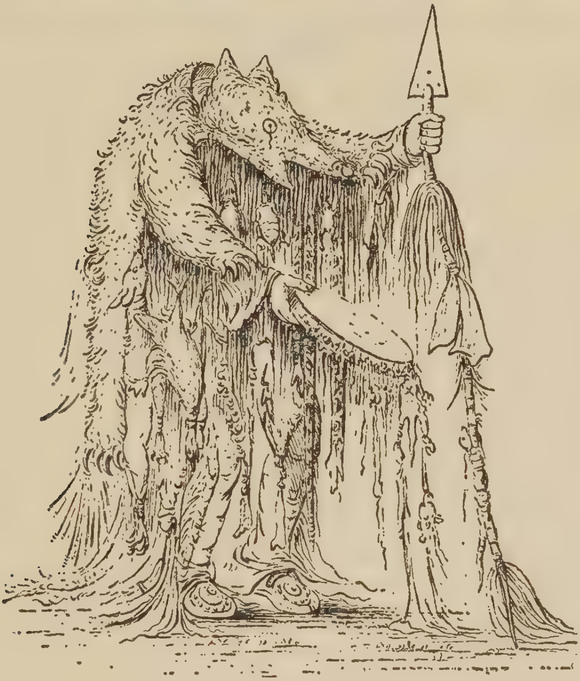

FIGURE 2.—An American Indian medicine man (from Catlin).

THE CONSERVATISM OF THE WITCH DOCTORS

As one would expect, the descendants of the witch doctor have not changed their technique very much through the ages, and if tomorrow they were to be called upon to cope with some terrible epidemic their methods would be practically the same as those of their savage ancestors. They would doubtless begin as they did in Biblical times, in the Middle Ages, and in the terrible winter of 1918, by fixing the blame on some group of persons who had offended the deity. Then there would be sacrifice and ceremony, solemn processions and pilgrimages and the making of vows, all undertaken with the hope of expiating sin and propitiating an angry God.

The average individual would keep his windows tightly closed at night to keep out the flying demons of disease, and he would certainly wear a protective amulet. If during the epidemic, a savage were to come to our shores with some explorer, he would see nothing new in all this, and could only approve heartily of every detail.

HOW PROGRESS IS MADE BY THE DESCENDANTS OF THE HERB DOCTORS

But now let us see what the descendants of the herb doctor did when, some 30 years ago, they were asked to send men to India to try to stop the bubonic plague which was raging there as it has done so many times in the past.

Did the physicians on that commission go into the temples and offer sacrifices to the hideous goddess of epidemic disease? No, they went to work with microscopes and guinea pigs. First, reckless of their lives, they opened the bodies of people dying with the plague, and studied the characteristic changes in the several organs. Then they put under the microscope a little juice from the enlarged glands in the groin, and always they found millions of tiny germs such as are never found in the tissues of normal persons. Then these germs were cultivated in glass tubes, and a drop of the culture was injected into a guinea pig, and when the animal sickened and died, the autopsy always showed lesions like those of the patients. And so, gradually, it became clear that the cause of the scourge was a living thing, a tiny germ which went into a man and kept multiplying until it killed him.

The next question was: How did this germ get into the people? Did they drink it or eat it or did it travel through the air? At this point the physicians were helped by a bit of knowledge that had been available for centuries, namely, that always, preceding an epidemic of plague, rats crawl out of their holes and die. Accordingly, hundreds of rats from the affected regions were caught and dissected, and in the sickly ones again there appeared the same lesions and the same little germs that had been found in the guinea pigs and in the patients. But how were the germs getting from the rats into the people? Soon the rats' fleas came under suspicion, and when some were removed from a rat dying of the plague and dissected, there again were the germs.

Then the scientists collected fleas from sick rats and put them on guinea pigs, and the pigs sickened and died of plague. They always got the disease also when they were left in cages on the floors of the huts where men were dying of plague and their fleas were hopping about looking for a new host. But when the cages were made of wire gauze too fine for the passage of fleas, or when ordinary cages were suspended some distance off the floor, too high for a flea to jump in, none of the guinea pigs succumbed.

At last, then, the essential facts about the disease were available, and bubonic plague could no longer range as a terrible scourge up and down the earth. Now, whenever a few cases appear in a city, health officers rush in and destroy rats and fleas, and the epidemic is stopped before it can get well started.

I wish I had time to tell more of the fascinating stories of the detective work that has been done in tracking down one little messenger of death after another, and learning so much about its life habits that health officers can destroy it or stop it from propagating, but I must hurry on. Those who have read Zinsser's delightful book on Rats, Lice, and History and De Kruif's Microbe Hunters already know how fascinating these stories can be.

EVERY WORTH-WHILE DISCOVERY OF THE PAST IS USED TODAY

I must hurry on to point out a fact which to me is a source of pride, and this is that every worth-while discovery ever made and remembered, and every accurate bit of information ever obtained and passed onward by the ancient herb doctors and by all true students of disease throughout the ages is used in scientific medicine today. I feel that every well-educated regular physician today is the lineal descendant and heir of the old herb doctor and primitive surgeon, just as every faith healer and every irregular practitioner who treats all cases alike, and every ignorant quack who treats by hocus-pocus of one kind or another is a lineal descendant of the witch doctor.

In my library I have translations of the two oldest medical papyri in the world. So far as scholars can tell, these two books date back to between two and three thousand years before Christ. The Smith papyrus was written by a remarkably modern surgeon who described the several types of fracture of the skull and the symptoms that go with each so clearly that we can follow him today. He sutured wounds and brought their edges together with adhesive tape; he knew that an injury to one side of the brain caused paralysis of the other side of the body, and he was often able to pick the patient who would die and the others who would probably get well. If he could only wake up today, to crawl out of his sarcophagus, I believe that a modern brain surgeon would find in him a helpful associate, and would defer to his judgment in the handling of many a wound.

The other ancient book, the Ebers papyrus, is not so satisfying today, because the witch doctor had too much to do with writing it. It is largely a collection of prescriptions in which drugs are mixed with unpleasant things such as the dried excrement of men and animals. Why did they use such things? In order to make the indwelling demon of disease so disgusted that he would get out and not come back. Actually some of the prescriptions were labeled "for the expelling or *terrifying* of the disease."

The Chinese have the same idea today, and in the Flowery Kingdom, when a man lies desperately ill his relatives will sometimes hire orchestras to keep up such an infernal din all day and all night that the devil causing the disease will get worn out from lack of rest and sleep and will depart for a quieter place!

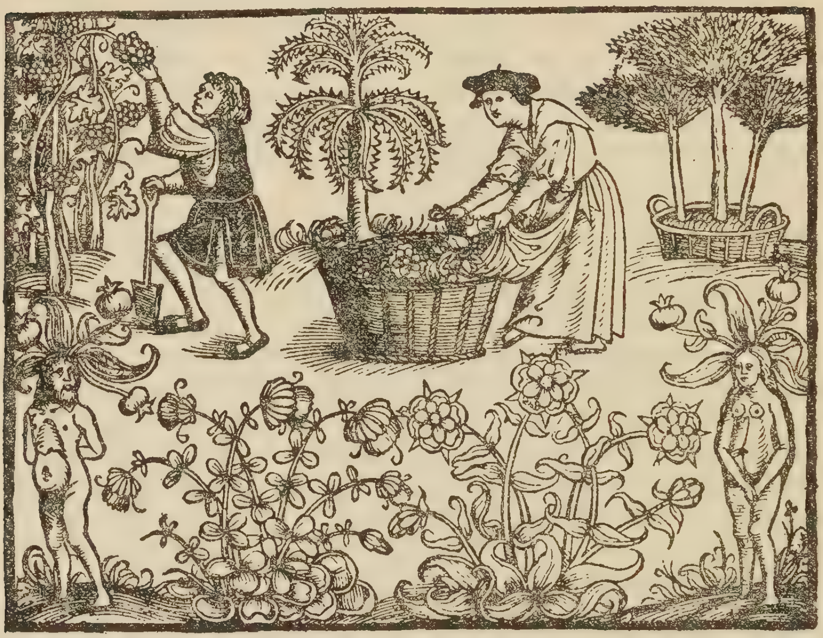

FIGURE 3.—Gathering herbs for the healing of the sick.

MIXTURES OF THE MAGICAL AND THE PRACTICAL

But to get back to the Ebers papyrus: As I have already pointed out, one finds there many instances of a very common medical practice, and this is the mixture of the magical and the practical. As one would expect, all through the ages the two systems have been combined more or less unconsciously by practitioners of the two types. Sometimes the witch doctor or the mental healer has used manipulations and even drugs, and the old herb doctor has taken care to gather his plants with a certain ritual or while mumbling spells, and only during certain phases of the moon. Furthermore, the herb doctor has often fallen from grace, scientifically speaking, and has prescribed a drug not because experience showed him that it was useful but perhaps because the astrologers believed that it and the disease to be treated were both under the protection of the same sign of the zodiac. Or perhaps because a walnut looks like a brain with all its convolutions, the old doctor gave powdered walnuts for insanity; or he gave red medicines for anemia and yellow ones for jaundice. Or he shaved elder bark downward to get a cure for vomiting and upward to get a cure for diarrhea!

Archeologists who, years ago, unearthed the archives of an ancient king of Nineveh found two letters of great interest to the medical historian. One was from a magician telling his master, the king, of his illness and begging that a physician be sent to him, the other was from a prominent physician who had prescribed for the king. Unfortunately, the treatment did not help, and later when the physician wrote, admitting that he did not know what the trouble was, he went on to suggest that while the local physicians continued to administer the medicines he had prescribed they had better also call in a magician.

And so it goes today; the faith healer calls in an obstetrician to help with a difficult case of labor, the spinopath prescribes diet and insulin for a diabetic, and the regular physician cures many a hysterical patient with a combination of pills, impressive apparatus, suggestion, and personal magnetism.

THE DRUGS PHYSICIANS USE TODAY CAME FROM ALL OVER THE EARTH

One of the most interesting things about the Ebers papyrus is that it shows us that away back in that ancient time physicians were already using many of the drugs that we prescribe today. Aloes, senna, castor oil, and epsom salts were being given for constipation, and peppermint and fennel for gas. To me one of the most curious prescriptions in the collection is the one for soothing a crying child. What do you think it contained? Why, nothing other than the opium which our Government had to ban from American patent soothing sirups some 25 years ago. Incidentally, some of you ladies might like to try one of the old Egyptian formulas for Countess So and So's facial cream, guaranteed to remove wrinkles! You will be interested to know also that the ancient Assyrians treated halitosis, they dyed their gray hair, they used mustard plasters, and they put a piece of raw meat on a bruised eye.

THE TRUE PHYSICIAN USES EVERYTHING EVER FOUND USEFUL

And this leads me to emphasize again the fact that a scientific physican today uses gladly any drug and any method of healing that he can hear of that was ever found really useful by anyone anywhere. Just let us go into a drug store and glance over the shelves. There we will find the castor oil, senna, ox gall, aloes, and opium which were used in ancient Egypt; another purgative, magnesia, came originally from an ancient city of that name in Greece; jalap comes from Mexico, and cascara from California; the aspirin which is so popular today is first cousin to the smelly oil of wintergreen which our grandmothers used to put on flannel and tie around aching joints, and quinine and cocain and ipecac come from South America. Digitalis, our most valuable heart medicine, came to us from an old English herb woman. When, 100 years ago, Dr. Withering found that this woman was curing some patients whom he had failed to help, he went to her and paid a good price for her secret. Then, like the true physician that he was, he picked out of her messy concoction the one essential drug and gave it freely to the world.

Lest this story about Withering serve to strengthen the belief that many persons have that it pays sometimes to go to a Chinese herb doctor or to an American Indian or to a Hindu or some other foreign healer because he must know many things that the American physician does not know, especially about medicines of vegetable origin, I will say that there may have been something in this idea long ago but there is not much in it now after all the years that pharmacologists have spent in studying drugs from all over the world.

ARE PHYSICIANS TOO CONSERVATIVE?

It is not complimentary to us physicians that thousands of people believe that if some layman were to discover the cure for cancer we would have none of it until forced to give in. Actually, a study of the history of medicine in the last 75 years reveals no basis for this belief. Our leaders have grasped eagerly at all of the great gifts that have come from men outside our ranks: From a physicist like Roentgen (X-rays), from a chemist like Pasteur (bacteriology), or from a dentist like Morton (anesthesia). In fact one of our worst tendencies today is to snatch the gift away from the giver before he has bad time to perfect it or to test it properly.

Every year the institution in which I work receives many letters from men and women who assure us that they have the cure for cancer and ask that we help them in getting it before the world. What these people fail to see is that if a man were to cure only a dozen patients with cancer scattered through the body, he wouldn't need to come to us for help. He would have to appeal to the police each day for a detail to keep the crowds in order on his front lawn.

Actually, of course, there is not one chance in a million that the cure for cancer will be found by a layman or some obscure physician working nights in his basement. Just as in gold mining, so in medicine, the time for picking up big nuggets is gone. Now the finding of such a thing as a cure for cancer calls for much work by groups of highly trained and well-equipped investigators, and success is likely to come only as the result of a series of discoveries, all made in big university laboratories.

HIPPOCRATES, THE FATHER OF MEDICINE

But to get back to the beginnings of medical writing; let me tell you a little about the greatest of all the ancient books. Really it is a series of books written in large part by Hippocrates, he whom we now call the father of medicine. He lived and worked in Greece some 400 years before Christ. He was a modern type of scientific physician in that he observed closely with a surprisingly open mind; he described what he saw, he recorded his failures as well as his successes, and he used everything of curative value that he could find. As one would expect from this, much of what he wrote so long ago is still of interest and value today. The few chapters that are of little value are the ones, probably written by disciples, in which the facts of observation were warped to fit one of those unprovable theories of disease which are still so popular with irregular practitioners today.

As many of you know, the Greeks looked upon the world as made up of four elements: Fire, air, earth, and water, and the body of four humors: Blood, phlegm, yellow bile, and black bile. These humors were affected by the four qualities of matter: Heat, cold, dryness, and moisture, and disease resulted when a humor became too hot or too cold, or too dry or too moist.

You who know something of modern chemistry and physics will say: "How silly," and yet these humoral ideas dominated and restricted and largely sterilized medical thought for 2,000 years. Even today, they affect our speech, and we say that a man is of a sanguine, a phlegmatic, a choleric, a bilious, or a melancholy nature, that he is good or bad humored, or that he has a warm or a cold temperament.

We physicians revere Hippocrates because he was the first man to teach, first, that many diseases clear up best if the physician does not meddle too much, and, second, that medicine can advance only when it breaks away from magic. Gradually, through the two milleniums before the birth of Christ, physicians had been coming to see that some diseases are due to injury and contagion and the wearing out of parts, but so far as we have a record, Hippocrates was the first to go the whole way and state that no disease is purely miraculous in origin. He would not exclude even epilepsy, which then was called the sacred disease, because of those terrifying fits which seem so obviously to be due to possession by a god or a devil.

And if through the ages, religiously minded people had only listened to Hippocrates and had given his successors the freedom to dissect, to perform autopsies, to experiment on animals, and to report honestly and fearlessly what they found, how almost certain it is that today medical knowledge would be hundreds of years ahead of where it is, with tuberculosis and cancer and arthritis perhaps only memories of the past.

THE EVER-PRESENT OPPOSITION TO MEDICAL ADVANCEMENT

But all through the ages a large section of the people in every country have kept saying, "No, you mustn't do this and you mustn't do that," thus making it hard or impossible for physicians to carry on their studies and their beneficent work for the relief of human suffering.

Really, aren't we human beings curious in our mental processes? In the middle ages they loved to hitch a dray horse to each of a man's hands and feet and drive these horses off in four different directions; they loved to strip off a man's skin while he was still alive, or to break his bones on the wheel, or to roast him over a slow fire; but just let the crowd which had looked on with approval and pleasure discover next day that an eminent teacher of medicine, trying to learn how better to help suffering humanity, had dissected what was left of the poor prisoner after the hangman was done, and they would turn in wrath to rend the impious wretch who had dared to so desecrate a human body!

But we must not smile at this in a superior way because even today, it is not always easy to get human bodies for dissection, and so bitter is the opposition of some animal lovers to the progress of scientific medicine, that in many cities the pound man does not dare to sell even a dead dog for study in the local medical school.

Just think of Aristotle, the greatest naturalist, and one of the greatest physicians of all time, having to admit that even with the backing of his pupil and patient, Alexander, the most powerful ruler of the then known world, he had been unable to dissect even one human body, and he had never seen a man's kidney or a woman's uterus!

It was not until the sixteenth century that the opposition to dissection of the human body died down sufficiently in a few Italian cities so that the great Vesalius was able to learn how a man is made inside, and to publish (in 1543) the first accurate book on anatomy. Obviously, until such knowledge was secured, the practice of surgery was impossible.

The next big step in the progress of medical science came in 1628 with Harvey's great discovery of the circulation of the blood. With this work was begun an era in which the functions of the many organs of the body were studied. In 1683, Leeuwenhoek discovered bacteria, and in 1719, Morgagni founded the science of pathology, which deals with the changes that are to be found in the bodies of persons dead of disease.

Later there came much progress in the differentiation of diseases by careful study of the symptoms and the physical findings, until physicians were able to distinguish malaria from typhoid fever, measles from German measles, diphtheria from croup, and appendicitis from ordinary stomach ache. Around 1877 Pasteur discovered the role that germs play in the causation of disease; protective vaccines and sera began to be made, and Lister showed how to banish suppuration from surgical wounds. In 1846, Morton and others discovered anesthesia, and surgery came into its own. Finally, with the development of bacteriology, there came wonderful triumphs in the prevention and cure of many of the infectious diseases that have plagued mankind.

THE LATEST PHASE OF MEDICAL PROGRESS

Today we are entering on a marvelous phase of medical development, and many seeming miracles are already being performed. The physiological chemist is having his inning, and every few months, someone discovers a new substance which has uncanny powers in the way of controlling growth and development. One of these substances makes giants, another makes midgets, another produces goiter, another makes the breasts of a virgin animal fill with milk, and other substances produce cancer at the will of the investigator. I feel sure that we are but on the threshold from which we shall soon glimpse great wonders.

As yet we do not know how to use curatively all these gifts of the chemist, and many are not yet even on the market, but with time and experience, there must surely come from some of them great benefits to the human race.

THE NEED FOR PROTECTING RESEARCH WORKERS FROM MISGUIDED PEOPLE

All of these great gifts of science are for you and your children. No one knows on what day some disease, as yet incurable, is going to strike down someone dear to you; and when that day comes the only hope your physician may be able to give you will be that in several laboratories in this country, or abroad, devoted men and women are working late into the night, hot on the trail of a cure for this very disease which now interests you so much. Under those circumstances the one thing left for you to do will be to pray that the discovery will not come too late.

Surely when such days of sorrow and anxiety come you do not want to have the door of hope slammed shut in your face with the announcement that certain people who care for animals more than they care for men and women and little children have succeeded in stopping work in those very laboratories in which this most promising research was going on. I am sure that most of you would never consent to such a thing if only you understood the problem, and if only you believed university authorities when they assure you that today laboratory animals are well taken care of, and, when operated on, are always kept under surgical anesthesia.

SUMMARY

In summing up, I would like to emphasize again that there are two types of medical practice that have been with us from the earliest times: One, that of the witch doctor and his heirs, and the other, that of the herb doctor and primitive surgeon and his heirs. One group relies on hocus pocus and some unprovable theory of disease; the other group bases its practice on observation and experiment, and uses every medical and surgical procedure of value ever discovered by man.

Even today the old witch doctor and his heirs hold the confidence of a large percentage of the population, and this fact greatly hampers health officers in their work. Although scientific medicine is forging rapidly ahead and working ever greater miracles of healing, it still has to fight its way against opposition from the many people who have been brought up to believe that diseases can best be treated by men and women who have had little or no education in medicine.

The story goes that once upon a time a man of God was treed by an angry bear which started to climb up after him. At first the minister said: "O Lord, help me," but as the bear kept climbing higher, he finally prayed: "O Lord, if you won't help me, at least don't help the bear." And so I close with this plea: That while teachers of medicine and investigators struggle to advance medical science and to supply you and your children with ever better and abler and finer physicians and with ever more efficient treatments for disease, will you please refrain from helping those many persons who are always trying to lower standards of medical education and licensure, and are always trying to stop the work being carried on in the research laboratories. As Dr. John Abel, that grand old man of American medicine, once said, "Greater even than the greatest discovery is to keep open the way to future discoveries."

1. MODEL MADE BY THE MILWAUKEE PUBLIC MUSEUM TO SHOW AN INDIAN MEDICINE MAN HEALING A PATIENT.

2. AN AFRICAN MEDICINE MAN CUPPING A PATIENT WITH A HORN.

3. AN INDIAN SWEATHOUSE IN THE AMERICAN SOUTHWEST.

NATIONAL AND INTERNATIONAL STANDARDS FOR MEDICINES[1]

By E. FULLERTON COOK, P. D., PH. M.[2]

Uniform standards for medicines are a recognized need for the medical world. Many substances now used in the treatment of disease must be exactly controlled as to strength, since they are often highly potent and require exact dosage if they are to produce the desired therapeutic effects. There is also the possibility of foreign substances finding their way into medicinal products, lessening their value or even adding an element of danger, and tests must be provided to guard rigidly against such a happening. This is not a new problem, but its solution is being attacked with increased energy and with a degree of success which carries confidence to the physician and the patient.

In this program for the production of medical substances of dependable quality there is, in the main, a commendable cooperation between all of those who share the responsibilities. This starts with the manufacturer, who must maintain a scientific staff of reliable and skilled experts to select raw materials and to test these materials for conformity to the established standards of purity and strength. Another group of trained technicians must be responsible for the production and quality of the finished products. These medicines are widely varied. Among them will be found chemical salts; new synthetic compounds of a complex nature, such as arsphenamine; anesthetics, like ether, which are so important an element in the safety of the surgical patient; or perhaps it is a biological product, illustrated by diphtheria antitoxin; or an ointment or a tablet, calling for skill and accuracy in manufacture. These are but a few illustrations from among the hundreds of different medicines employed today.

After production and sale, again the established standards apply and at this time with greater significance than before, since the tests are likely at any time to be made by the laboratories of enforcement officials with the possibility of substances being found unofficial and the manufacturer being charged with the adulteration of his products. This is all in the background of the production of modern medicines.

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[1] One of the 1936 series of Popular Science Lectures of the Philadelphia College of Pharmacy and Science. Reprinted by permission from the American Journal of Pharmacy, May 1936.

[2] Chairman of the U. S. P. Revision Committee and Director of the Pharmaceutical Laboratories at the Philadelphia College of Pharmacy and Science.

But you may be asking how this has developed. How were these medicines selected? Who discovered that some drugs are cathartics, that others cause a profuse perspiration, that another slows and strengthens the heart, while still others stimulate respiration or raise the blood pressure or perhaps relieve pain? We are particularly interested in knowing who determines the identity and quality of the medicines needed by modern physicians. What happened in past centuries is vaguely indicated by the records of the past.

In recent years this information about the value of new medicines has come through scientific researches in a modern laboratory, but the foundations were only slowly built up, through the centuries, by individuals who often worked alone, making crude observations and deductions and having few opportunities, and often no desire, to record the results for the benefit of others. But fortunately there are remarkable exceptions and to these pioneers the world today acknowledges a debt of gratitude which is inestimable.

Back of all of this modern program is an interesting record. It is not necessary to review this in detail to remind you that the elaborate organization of today had its roots well grounded, first in tradition and then in proven history.

EARLY PHYSICIANS

The initial incentive of the pioneer healer is credited to an ennobling desire to relieve suffering. True, in every age the charlatan has exploited the sick for pecuniary reward, yet the initial force, through all of history, seems to spring from those pioneers who truly labored to heal the sick and were a part of the religious orders of the time, theirs usually being a priestly service. With the effort to help those who were ill, came some knowledge of the nature and causes of disease and with this there slowly evolved methods of treatment with all manner of strange medicines.

The early physician made slow progress; his knowledge was limited, the medicines were crude, he could not enforce treatments, and he had poor opportunities to study effects. Yet it is surprising how many valuable substances had been discovered even when the oldest known records were revealed. Of necessity there often entered into the treatment that which was associated with the mysterious or the occult, often with incantations and prayers—how natural that the influence of the deity should be invoked when the priest treated the sick.

EARLY MEDICINES

What medicines were used in the period of 4000 B. C., of Babylonian history, is not known, but tradition tells of the labors of the physician and of his associate who is supposed to have prepared the medicines. Legend recounts the story of an Egyptian physician known by the name of Imhotep who lived about 3000 B. C., and he is reputed to have used many combinations of medicines.

That there is some justification for these unverified traditions of remote civilization is borne out by the discovery of an almost perfect Egyptian manuscript dated 1552 B. C., which consisted of a collection of medicinal formulas. This is called, after the name of the discoverer, the Ebers Papyrus, and is evidently a record of the medicines known at the time when Moses lived; it must have represented the accumulated knowledge of the centuries. Here are recorded about 700 simple drugs representing the vegetable, animal, and mineral kingdoms, and while many were impossible and worthless, it is remarkable that the list included substances which find a place even in the latest lists of present-day medicines. Among these were turpentine, castor oil, anise, henbane or hyoscyamus, poppy capsules, which were the forerunner of opium, aloes, myrrh, cassia, gentian, colchicum, and squill. Among the mineral substances were iron, lead, magnesia, nitre, vermilion, copper sulphate, sodium carbonate, and sodium chloride.

The use of precious stones, finely divided, was a form of medical treatment. These were ordered of various types and prices, depending upon the ability of the patient to pay. For the wealthy the emerald or lapis lazuli or the sapphire were directed, but for those less able to pay green porcelain or a similar appearing colored glass was acceptable.

This belief in the medical value of precious stones did not end with the Egyptian era for they are found in the pharmacopoeias of Europe of the seventeenth and eighteenth centuries, showing how tradition and superstition can be continued for centuries.

Animal drugs were also present in abundance. It would seem as though the more offensive the more merit was anticipated. Certainly this early physician was willing to try every material at hand, hoping that he might discover that God-given remedy which he believed was provided as a cure for every disease. It would seem also as though they believed that special merit resided in any substance which had an offensive odor and so among the recorded animal drugs were lizards' blood, swine's teeth, putrid meat, stinking fat, moisture from pigs' ears, excreta from many sources, including flies, and other substances even more revolting. Some of the formulas were very simple and evidently mild in action, as, for instance, one for headache calling for frankincense, cummin and an unidentified berry, all mixed with goose grease and applied externally.

On the other hand, some formulas were exceedingly complex; one for a poultice containing 35 ingredients with complicated directions for compounding. Evidently worm medicines were in demand, for there were formulas for medicines to remove hookworms, tape worms, seat worms, and intestinal worms.

Many forms of medicines had also been developed at this early period, including infusions, decoctions, fumigants, inhalations, gargles, injections, pills, powders, triturations, salves, plasters, confections, and poultices. Here indeed was the forerunner of the modern pharmacopoeia and a real attempt to establish some form of standards for the medicines then in use.

EARLY FORMULAS AND STANDARDS

Other medical papyri of this or even earlier Egyptian periods have since been discovered, and some specialize in magic and sorcery which so frequently accompanied medical treatment.

While there is less known concerning the medicines of ancient China, probably because of less research into their literature, there is knowledge of a pharmacopoeia-like compilation of Chinese formulas called the Great Herbal, which goes back beyond the Christian Era. It is made up of 40 volumes and boasts of at least 1,000 authors, including as the original authority the Chinese mythical god of medicine, Shen Nung. This work contains several thousands of prescriptions and many strange substances such as toad's eyelids for coryza. This particular drug might indicate a keenness of observation which is almost uncanny, for modern investigations prove the presence of an adrenalinlike substance, secreted by a gland near the eye of a Chinese toad, and one of our modern treatments for coryza sprays the nostrils with solution of adrenalin.

Assyrian and Babylonian records also show about this same period a knowledge of medicines much the same as that of Egypt, evidencing the manner in which information is carried from country to country. Cannot one well imagine a wanderer upon the earth, carrying perhaps a secret recipe, in which some mysterious powder enters; a substance which may come from far-off India or even China, by the routes of ancient commerce, and his selling it to physician priests far and wide for perhaps a fancy figure?

And so there is found, even in the earliest civilizations, a well-marked tendency toward established medical formulas, including names, symbols, and descriptions for hundreds of substances tried and recommended for the cure of the sick.

The great civilizations of Greece and Rome, covering more than 1,500 years, were built upon the foundations laid by the still earlier races. They rose to heights of accomplishments in literature, architecture, philosophy, government, and conquest not before dreamed of and they influenced the life and habits of all subsequent western peoples. This is equally true in the field of medicine, and the names of those who turned to the healing arts and recorded their observations and teachings dominated medical practice in Europe for hundreds of years.

Tragically, the later barbaric hordes or the fanatical religious groups who overran these countries in the middle ages destroyed countless manuscripts which could have added to the exact knowledge of the time, but enough was saved to preserve abundant evidence of the remarkable accomplishments of this productive period. So blended are the earlier records that it is difficult to separate the mythological from the real.

Among the Greeks, Apollo was the God of Medicine, but Chiron, the Centaur, by mythological tale, was credited with having brought to man the first knowledge of the composition of medicines and he is reputed to have taught the other mystical characters what they knew of the healing art, including Aesculapius, who lived about 1250 B. C., and who is the patron saint of medicine.

HIPPOCRATES AND LATER GREEK PHYSICIANS

Prior to the time of Hippocrates, the temples of Aesculapius were the centers of medical knowledge, and the priests practiced the healing art although it apparently depended little upon medicines. Charms, incantations, and prayers were the important elements in treatment, although the temples were situated in the center of lovely groves where springs abounded and where the patients were subjected to vigorous physical treatment.

Historically we owe to Hippocrates, a Greek physician born 460 B. C., the most exact knowledge of Greek medicine. He had apparently been steeped in the lore of tradition and mythology and had learned of the medical practices of previous civilizations, but his was that rare type who observes accurately and thinks clearly, and his writings sharply distinguished between the real and the supernatural and recorded for future generations the knowledge which he had acquired in his long and active life.

In his writings he named about 400 medicinal substances and is said to have made his own preparations. While Hippocrates did not compile what might be called a pharmacopoeia, his books told of the uses of medicinal substances and how to combine them, and since his teachings influenced medical practice for at least 2,000 years, his place in the fixing of standards for medicines cannot be exaggerated. During this period many new schools of medical thought arose and and in most of them medicinal substances found a place.

In the post-Hippocratic period, reigned the famous Mithridates Eupator, King of Pontus. After his defeat by Pompey, the formula for his famous medicine was released. The Confection Mithridates was improved upon by Damocrates, physician to Nero, and later by Andromachus, also a body physician of Nero. This became the most famous medicine of history. It was also known as Confectio Damocrates and as Theriac (as he added flesh of vipers—the name coming from Tyrus, a snake) and 1,600 years later the formula was included by Valerius Cordus in his dispensatory. At that time the traditional formulas contained about 60 ingredients.

Dioscorides was another Greek physician whose writings were long a dominant factor in European medicine and who was probably a contemporary of Claudius Galenus, commonly known as Galen. Galen was one of the most famous physicians of all history. He became a celebrated medical authority. He lived at the time of Marcus Aurelius and traveled widely, practicing his profession as he went. While born a Greek, he became a citizen of Rome. He was a voluminous writer on medical subjects as well as an experimenter in the preparation of medicines, many of which he made from vegetable drugs, and this class of products is still associated with his name, as galenicals.

ROMAN ERA

The first Roman to prepare a formulary was Scribonius Largus, physician to the Emperor Tiberius, about 45 B. C. This volume was called Compositiones and was more nearly of the type of the later pharmacopoeias of the fifteenth, sixteenth, and seventeenth centuries. Besides the books which were being written, standard formulas were developed by individuals and passed on to future generations.

Reference has already been made to the Confectio Damocrates or theriac. Another formula, the theriac of Nicander, was written in verse on a stone in the temple of Aesculapius on the island of Cos, the birthplace of Hippocrates. Another theriac was that of Philon of Tarsus. This was written in verse that it might be more easily remembered. Its most rare ingredient was the "flesh of vipers" and this remained a part of the published formula 1,500 years later. Another ingredient which might be misunderstood was written as "the red hair of a lad whose blood was shed on the fields of Mercury," but this was only the picturesque way to write "saffron." Other ingredients were opium, pyrethrum, euphorbium, pepper, henbane, spikenard made into a confection with honey. It was originally intended as an antidote to poison, but was widely used as a remedy for colic.

Then came the decline of Rome and its fall in the fifth century under the attack of the barbarians from the north who suppressed and destroyed these earlier civilizations. In the following centuries under the influence of Mohammed there began the period of Arabian supremacy. Egypt was overrun and in 642 Alexandria was captured, and then the Arabs swept on through Spain and dominated most of the habitable world for 500 years. Bagdad became an important center of learning and also Cordova at a later period.

ARABIAN PERIOD

Fortunately, some manuscripts of Hippocrates and Galen had escaped the wholesale destruction of the libraries of Alexandria and were now translated into the Arabic together with other Greek scientific and philosophic writings. The early intolerance of the Arabian caliphs was abandoned, and with the establishment of universities at both Bagdad and Cordova, teachers from the western world, Christians, Jews, and Pagans, were encouraged to bring there the sciences in which they were interested. Medicine, pharmacy, and chemistry were especially encouraged, and under Caliph Haroun al-Raschid, about A. D. 780, hospitals and dispensaries and separate pharmacies were established in Bagdad.

An outstanding contribution to medical standards came about this time from Mesué Senior, who was head of the Medical School of Bagdad during the reign of Haroun al-Raschid. His formulary was translated into Latin as late as the fifteenth century and became the model for the first London pharmacopoeia. He was opposed to the violent purgatives of earlier medicine and is said to have introduced the mild laxatives senna, cassia fistula, tamarinds, and jujube. His pupil, Johannitus, translated Galen's books into the Arabic, from which they were later translated into Latin.

The head of the hospital at Bagdad in 870 was a famous physician-pharmacist commonly known as Rhazes. He wrote voluminously on medicine and pharmacy and especially exposed many impostors. Two hundred years later another teacher, Mesué Junior, developed in Bagdad, whose work entitled "Grabadin", which was an abbreviation of an Arabic word meaning compound medicines, was used as a pharmacists' manual for 500 years, going through hundreds of editions. It consisted of many formulas arranged in classes, and many preparations of the earlier European pharmacopoeias are traced back to this formulary.

Another eminent physician of the Arabian period was Avicenna, of the tenth century, and also Maimonides, the latter born at Cordova in 1135. Maimonides is most famous for his oath and prayer, setting forth an idealistic code of ethics for the physician and the pharmacist. It is almost as famous as the Hippocratic oath.

Contemporary with Haroun al-Raschid and the golden era of Bagdad, Charlemagne reigned. He encouraged the growing of herbs and the making of medicines by the monks. The herb gardens of the monasteries of Europe during the eighth and ninth centuries developed the vegetable materia medica and also a greatly increased knowledge of botany. The word "drug" also appeared about this time, meaning a "dry herb." With this development of the herbal garden there also appeared manuscripts dealing with drugs and their use in medicine, but they mostly dealt with charms and spells and contributed little to the knowledge of medicine.

During the ninth to the eleventh centuries an opportunity was offered at Cordova for the establishment of a separate Jewish academy, and its influence rapidly spread through Europe, where many Jewish physicians were welcomed and successfully practiced their profession. One of the best known Italian Jews of this period was called Donnolo, and his "Antidotarium" contained descriptions and formulas for many drugs and preparations.

ELEVENTH TO FIFTEENTH CENTURIES

About the middle of the eleventh century there began a reawakening of interest in arts and sciences throughout all of Europe. The Norman Duke Robert captured Salerno in 1076 and encouraged the development of the university so that it became the leading educational center of middle Europe. During the next 200 years other universities were established—Paris, Bologna, Oxford, Cambridge, Padua and Naples—and in all of them medicine and pharmacy were taught.

The medical director of the Medical School at Salerno at the beginning of the twelfth century was Nicholas Praepositus. His "antidotarium" became the standard for pharmaceutical formulas for centuries, and he introduced the apothecaries' system of weights and measures much as it is known today.

A notable advance came in 1224 when Frederic II of Sicily established a regulation requiring all physicians and compounders of medicine to be examined and licensed by the Medical School of Salerno. The pharmacists, or as they were then called, the "confectionarii," were required to swear that they would prepare all medicines according to the instructions of the antidotary of Nicholas Praepositus. The drug dispensers were under strict inspection, and some preparations had to be made in the presence of inspectors. Any attempt to defraud subjected the offender to confiscation of his property and an inspector caught violating the law was subject to the death penalty.

During the next period, from the twelfth to the fourteenth centuries, many additional universities were established, but there was little original medical knowledge developed, although during this time frightful scourges swept through Europe, these including leprosy, ergotism, black death or plague, and later syphilis. It is estimated that 25 percent of the human race died from plague during this period. This era is noted, however, pharmaceutically, for the establishment of regulations for pharmacists and the setting up of independent pharmacies and guilds governing their practice throughout much of the European world.

FIRST REAL PHARMACOPOEIA

In 1498 there was issued in Florence the first real pharmacopoeia. This was compiled by a commission appointed for the purpose. It was made up mostly of the formulas of Galen, Mesué, Avicenna, Rhazes and Nicholas Praepositus. A second pharmacopoeia appeared at Barcelona in 1535. It not only contained formulas, but also the rates at which drugs should be sold.

In the sixteenth century an "antidotary" appeared in two volumes by John Jacob Wecker. In the second volume, of almost 900 pages, are printed thousands of formulas with the authorities for many, and here are included most of the famous names in medicine for the past 1,200 years. Here the Theriaca formula is attributed to Galen, and it included 60 or more ingredients with a full page of directions of manufacture. Because Theriaca was believed to be a specific cure for the plague, it was largely in demand. Then came the compilation of formulas by Valerius Cordus, published by the order of the city of Nuremberg in 1546. This was more of a dispensatory type than a pharmacopoeia, although it was long looked upon as the first real pharmacopoeia.

A similar compilation of formulas appeared in 1564, known as the Augsburg Pharmacopoeia, and it also had much influence over later pharmacopoeias.

LONDON PHARMACOPOEIA

But now came an outstanding event in pharmacopoeia making—the appearance of the First London Pharmacopoeia in 1618. It had been sponsored by the College of Physicians of London, and special committees were appointed as early as 1589, but these committees had to be reorganized and it finally appeared almost 30 years later. It contained 1,028 simple drugs and 932 preparations and was therefore quite an extensive work.

It did not depend wholly upon the older formulas handed down for centuries, but included many prescriptions attributed to contemporary authorities. Here are found many familiar medicines of today, such as potassium bitartrate, sulphur, potassium nitrate, calomel, lead acetate, antimony oxide, aloe, calcium hydroxide, scamony and squill. There were also many revolting substances, especially among the animal drugs.

The appearance of the London Pharmacopoeia stimulated the physicians of many other cities to issue pharmacopoeias. In the list are Paris, Antwerp, Brussels, Edinburgh, Dublin, and others under the names of countries, as Prussia, Saxony, Württemberg, and Spain.

PHARMACOPOEIA OF THE UNITED STATES

It was chiefly the Pharmacopoeias of London and Edinburgh, however, which inspired the first edition of our own United States Pharmacopoeia.

To now turn to our own pharmacopoeia. We are accustomed, in this generation, to seeing strings of the letters of the alphabet everywhere we turn. This is so common that one wonders if there might not be a deficiency and a need for new symbols to express the many governmental or other activities constantly before the public. This custom was widely established during the World War (1914–18), largely in the British Army, but has developed to a maximum in our own period of the New Deal (1933–36). However, long before the alphabetic symbols of the World War or the New Deal were thrust upon us there have been known and used by physicians and pharmacists three significant letters. They are "U. S. P." Today these are often seen by the public, and should have a meaning to the everyday man commensurate with the importance which they hold in relation to health. "U. S." naturally means the United States. "P." stands for a word long established but not often used by the public—the word "Pharmacopoeia."

These letters, "U. S. P.", are frequently found upon labels of medicinal substances. They follow the title and indicate that the material in the package or bottle maintains the standards of strength and purity established by the Pharmacopoeia of the United States. When a pharmacist orders medicinal substances for use in manufacture or in the filling of prescriptions, he usually writes "U. S. P." on the order. By this means he is assured of a high-grade product, uniform in quality and suitable and safe for medicinal use. If, when the layman enters a drug store and purchases certain of the commonly used and well-established home medicines, he insists upon having U. S. P. quality, there is the same protection for him as for those connected with the professions.

Uniformity in quality such as is now insured by U. S. P. standards was not always obtainable. The development of superior quality and consequent efficiency in medicinal substances represents many years of cooperative effort on the part of physicians, pharmacists, and the Government. We are fortunate in having at our command this accumulated experience and an organization which establishes standards for medicine within the United States.

As has already been intimated, it was customary in the American colonies for physicians and apothecaries to employ the pharmacopoeias of Europe as the basis for the medicines. These were generally recognized as standardized. In the English colonies, the Pharmacopoeias of London and of Edinburgh were employed, but soon after the establishment of the Republic the possibility of having a national pharmacopoeia for the United States of America was recognized and given serious consideration. What is often spoken of as the "First American Pharmacopoeia" was a small book or formulary compiled in 1778 by Dr. William Brown for use in the hospitals of the United States Army. The limited scope of this publication accounted for the failure to have its use extended into general medical practice. However, the physicians in general practice were ambitious to establish their own standards, and in 1787 a committee of the College of Physicians in Philadelphia was appointed for this purpose. There is no record of any report from that committee.

In 1805 the Massachusetts Medical Society was responsible for the issuance of what became known as the Massachusetts Pharmacopoeia, but this had only a local use and also was limited in its scope. In the main, the Massachusetts publication was based upon the Edinburgh Pharmacopoeia. The subject continued to be agitated, and various medical centers prepared preliminary compilations embodying local or native plants, the Medical Society of South Carolina having done this as early as 1798. The stimuli resulting from the appearance of the pharmacopoeia sanctioned by the Medical Society of Massachusetts was the nucleus for increased interest, and in 1815 the physicians and surgeons of New York had organized for the preparation of their own pharmacopoeia. This appeared in 1816.

To one man is universally give the credit for the inspiration and the organizing ability which brought into existence the first edition of our national pharmacopoeia. That man was Dr. Lyman Spalding. He had long recognized the importance of this step and is known to have discussed the question with Dr. Barton, of Philadelphia, while visiting in that city in 1805. Dr. Barton was a professor of materia medica and editor of the Medical and Physical Journal. His botanical gardens had at that time acquired world fame and in these gardens he had particularly cultivated native medicinal plants. Dr. Spalding presented a well-formulated plan to his New York colleagues in January of 1817, and a committee was appointed to assist him in developing the program. This committee met and invited medical organizations in America and abroad to offer suggestions and to lend their support. In accordance with their plan, sectional conventions were called to consider the proposal to establish a pharmacopoeia and each to send plans and outlines. Two of these sectional conventions met; one in Boston and the second in Philadelphia. A third called as a "Southern Convention" failed to secure a quorum, but arranged for delegates to attend the Washington convention as did also those invited to form a "Western Convention."

At the preliminary meetings in Boston and in Philadelphia very complete drafts for a proposed pharmacopoeia were prepared, the contents being largely based upon the then current pharmacopoeias of London, Edinburgh, and Dublin.

MEETING OF 1820

Following out the plan, representatives of these sectional conventions met in Washington, D. C., in the spring of 1820 and, after giving consideration to the various proposals, appointed a committee to write and edit the new Pharmacopoeia. Dr. Spalding assumed the responsibility of chairmanship and editor, several meetings were held, and the new pharmacopoeia was issued the following December. This new book of standards received the general approval of the medical profession, and while there were some criticisms, the start had been made for national agreements upon the titles and quality of American medicines. Over 100 of the titles in the primary list of medicinal substances in this first pharmacopoeia have been carried forward into succeeding revisions, showing the careful character of the selections and the rather remarkable knowledge of medical substances at the beginning of the nineteenth century.

One important feature of this book was the number of formulas for chemical substances by which the apothecary could prepare or purify them for medicinal use. The list of vegetable drugs consisted mainly of titles and definitions with little effort further to standardize the substances. There were, of course, formulas for making the popular preparations of the day. In accordance with the traditions of the profession as exemplified by the pharmacopoeias of that day, the text was printed on the left-hand page in Latin, with the translation in English on the right-hand page.

A feature of Dr. Spalding's original plan was the reassembling of the convention in each succeeding decennial year for the consideration of further revision of pharmacopoeial standards. This program was carried through successfully from decade to decade, with a widening interest, and with the addition of pharmacists to the delegates at the 1850 convention. From 1820 to 1870 the general style of the Pharmacopoeia remained the same except for the omission of Latin, beginning in 1840, and the addition of new medicines as these were developed.

During this time the retail pharmacists made most of their preparations from selected raw material, often collecting their own vegetable drugs, and there was no need for tests to prove that the official products conformed to the standard. However, when the time came for the preparation of the Pharmacopoeia of 1880, a new condition was rapidly developing. There had now grown up in the United States a number of chemical and pharmaceutical manufacturers who were selling ready-made medicines to the retailer, and this relatively new problem made it necessary to introduce tests and standards to check the products which were being sold. This began a new phase in pharmacopoeial activity and largely altered the appearance and character of the book. There was the same careful selection of therapeutically important substances, based upon the needs of the medical profession, and in many instances there remained the manufacturing formulas for those who desired to use them, but the outstanding new feature was a series of tests and assays whereby the finished product could be subjected to a check upon its quality and even rejected if there was failure to meet the requirements.

With the expansion of the services of the manufacturing pharmacist and chemist, the Pharmacopoeia dropped most of the methods of production for chemicals and also many manufacturing processes for pharmaceuticals. These were excluded because it was now no longer possible to make them in the shop of the apothecary with any degree of economy, but proportionally the tests for strength and quality increased. Tests and assays have now been still further expanded and are an essential part of the modern pharmacopoeia. Up to this time, practically all of the important nations of the world had their own pharmacopoeias. With the increase in travel throughout the world there began to be agitated, during the latter part of the nineteenth century, the idea of an international effort for the standardization of medicines. The fact that patients who had secured medicines in one country later had difficulty in having their prescriptions renewed elsewhere was the excuse for such agitation. Great variations in the strength of preparations and even in the quality of drug was shown to be true in different national pharmacopoeias, and considerable effort was made to develop what would be known as an international pharmacopoeia. But this did not meet with general favor. This is natural, since national pride enters into the publication and also fundamental differences in the practices of various nations, so that strong opposition developed immediately.

The nations were not able or willing to agree upon one book of standards or formulas for medicines, and the idea of an international pharmacopoeia was abandoned. However, there came a happy suggestion, originated apparently by the pharmacists of Brussels. This embodied the idea of setting up international agreements for specific items, these to be the more potent medicines. On the invitation of the Belgian Government, the various nations of the world were asked to send delegates to Brussels to consider the establishment of such standards, and the first conference was convened in 1902.

By the plan announced, no nations would be influenced or persuaded against their wills to adopt in their forthcoming pharmacopoeias the recommended strengths. On the other hand, there would be many advantages to each nation to have uniformity in the strength of the more potent remedies, and the plan met with wide favor—retaining as it did the inherent integrity of each national standard.

By this agreement, all preparations containing arsenic were made of uniform strength. Many other preparations which would be poisonous if taken in excessive dose were brought to a uniform degree of strength. For instance, a very important class of preparations—the tinctures—were made of 10 percent strength for all of those which were highly potent, including preparations of such drugs as digitalis, capsicum, opium, aconite, etc. Prior to this agreement, the strengths of potent tinctures varied from 5 to 50 percent, and the new uniformity thus eliminated the danger of abnormal dosage or inferior therapeutic effects which might have resulted from the filling of a foreign prescription in a local apothecary shop. Tinctures of less active drugs were made 20 percent.

THE FEDERAL FOODS AND DRUGS ACT

During the first 80 years of the existence of the Pharmacopoeia of the United States, conformity to its standards was voluntary. It speaks well for the codes of ethics influencing the medical and pharmaceutical professions that this national standard was widely followed and the purpose of the pharmacopoeia thus carried out. However, for the maximum of efficiency, it was believed important to enact laws which would enforce uniformity in standards. Several States had undertaken the passage and the enforcement of such laws, and the question became a national issue. Under the aggressive leadership of Dr. Harvey W. Wiley, Chief of the Bureau of Chemistry of the Department of Agriculture, and with the enthusiastic support of many physicians and pharmacists, there was introduced into Congress and successfully passed what has become known as the Federal Food and Drugs Act. This law was actually passed in 1906. Under this legislation it is required that official medicinal substances shall maintain the strength and conform to the purity standards of the Pharmacopoeia when sold or dispensed as medicines under the official names. There is a provision in the law which permits a modification of the official standards if this act is clearly indicated upon the label. This is known as the "variation clause" and is intended to provide for justifiable modifications in official standards such as half-strength tincture of iodine. The basic principle underlying this law is represented by the principle that, "The product must always be true to its label statement."

Following the establishment of this national-drug law, which is operative only in interstate commerce and in the District of Columbia and the Territories, most States passed similar laws to enforce the uniformity of standards for medicines within that State. Inspectors were appointed and specially trained chemists having established chemical laboratories were developed to enforce these laws, and a high degree of uniformity in medicines was thus established. Recently, Congress and the medical and drug world have been agitated by proposals that the Federal Food and Drugs Act be revised to be made more effective and also to include cosmetics within its scope. So far this law has not been passed, although several drafts have been given careful study and are now pending in Congress.

There is wide approval of such added legislation in the interest of public health, and those who are affected have largely cooperated in trying to develop appropriate and enforceable laws.

KEEPING THE STANDARDS MODERN

If the descriptions and formulas established for medicines in 1820 were in force today they would be entirely inadequate. New medicinal products are constantly developed through the activities of medical research. Should these prove to be important therapeutic agents, they properly find a place in the next pharmacopoeia and they call for properly developed standards. Products which have long been official frequently need modified tests to control their degree of purity or to better determine their strength. Again, added tests are sometimes needed to check newly discovered foreign substances which appear in compounds, perhaps because of modifications in manufacturing procedure. In other words, there is a constant necessity for reviewing the standards of older compounds as well as establishing tests for those which are new.

In the last Pharmacopoeial Convention, held in 1930, the delegates were mostly from the national and State associations and the colleges of both medicine and pharmacy. There were also representatives of the departments of the Government interested in health. These delegates developed the general policies governing the pharmacopoeial revision and also elected the members of the committee of revision to revise the standards and a board of trustees to direct the business side of the organization. The committee of revision of the present pharmacopoeia numbers 51 with a large group of auxiliary members selected for their special ability or knowledge in specific scientific fields. The medical members of the committee are largely held responsible, in the initial stages of revision, for selecting the medicinal substances which are considered of sufficient importance to be officially recognized.

The other members of the committee are pharmacists, chemists, botanists, bacteriologists and others representing the many related sciences. These members assume the responsibility for fixing standards for those substances which are admitted. There is need for thorough knowledge of the botanical characteristics of drugs and the setting up of standards for these. Here the microscope is an important scientific instrument in determining the quality and identity of the drug. The plant structure or some specific microchemical test giving distinctive colors or crystals or reactions enter into the preparation of standards.

In a number of instances where there are specific crystalline principles of the alkaloidal type, as in cinchona, which contains quinine and related alkaloids, as in nux vomica with its active principle strychnine, or in opium with morphine, codeine, etc., as the active agents, or in drugs of a similar character, tests are required by which these highly potent crystalline principles are extracted and their quantity actually weighed or otherwise estimated. This method of procedure is known as a "proximate assay."

In other drugs the activities are represented by substances which cannot be extracted or weighed but the potency must be measured by their action on animals. For instance, the very important drug ergot has within it various alkaloidal substances which produce distinctive physiologic effects upon living tissue. One test, which has been widely used, depends upon the effect of one of these principles upon the comb of a rooster. The change is due to the contraction of the capillaries or small blood vessels in the comb, causing it to become darker in color, and the degree to which this is affected by known quantities of the drug, in comparison with a standard, is one means for determining its potency. Other biological tests, registering the actual effect of a drug upon an animal or one of its organs, must be used for the standardization of digitalis, aconite, pituitary, epinephrine and similar important and powerful drugs. In other cases, the absence of toxicity in a chemical such as arsphenamine is determined by injecting the substance into mice to assure freedom from dangerously toxic substances which might otherwise prove fatal to a patient. Other medicinal agents, chemical in nature, are standardized by many ingenious tests.

Frequently a reagent will bring about a distinctive color or a precipitation or cause some other reaction which indicates identity. Then the substance is usually tested for foreign substances or adulterants and again distinctive reactions result when standard reagents are added, and these indicate the absence or the presence of such foreign substances.

In the manufacturing of chemicals there is always danger of introducing foreign materials. These may come from the apparatus used in manufacture, or from the chemical substances entering the process, or from other causes. So there are usually tests to exclude common adulterants. Another series of tests for almost all chemical substances deals with the identity of the product.

Chemicals are also frequently assayed by quantitative methods to determine their percentage of purity. Sometimes this is a simple chemical reaction such as the neutralizing of an acid with an appropriate amount of standard alkali, the indicator showing by color the point of neutrality and the calculation proving the degree of purity. Other assays are much more complex but the objective is identical and the tests so applied that excessive amounts of foreign substances will be detected or the official quality of the material under investigation verified. Frequently the ingenuity of the chemist is tried to a high degree in maintaining accuracy and skill in carrying out these tests. Some assays are relatively simple, as for instance in the ointment of mercury in which the fatty vehicle is dissolved by a suitable solvent, leaving the metallic mercury which can be dried and weighed to determine the strength of the original ointment.

In recent years, a new series of tests have been developed dealing with the vitamin activity of cod-liver oil. Only a few years ago it was demonstrated that there existed in this remarkable oil at least two factors which were essential for health. A deficiency of either of these in humans, and especially in children, is often the cause of serious physical defects. The amount which is present in the oil under examination is determined by feeding it in measured amounts to rats which have been kept on a diet free from the vitamin under test, and with the animal consequently suffering the characteristic deficiency diseases. The amount necessary to restore the animal to health indicates the amount of the vitamin present. The results of such assays are based upon the average of a number of tests and can only be decided when they have been carried out over many weeks of experimentation.

That these official tests for identity, purity, and strength may be effectively carried out, by both the producer of a product and the officials enforcing these standards, there is the necessity of thorough training and experience for the scientist carrying out the tests. This army of experts, guarding the manufacturer and his products, and those supporting the activities of officers of inspection in the Federal and State Governments, represent a large group of scientific experts who are actively engaged in an important part of the health program.

The members of the committee of revision serve voluntarily as a contribution to the professions and to public welfare. This principle of voluntary service brings about an unusual degree of cooperation between the enforcement officials of the Government and the manufacturers of medicinal products and the experts in these fields associated with colleges and universities.

NATIONAL FORMULARY

While emphasis has been placed upon the Pharmacopoeia as the book which fixes the standards for medicines within the United States, a second book called "The National Formulary" (abbreviated "N. F.") is also recognized under the Food and Drug Acts, and medicinal products sold under titles found in that book must conform to its standards unless a variation is clearly indicated on the label.

The U. S. P. and N. F. are not duplicates, but each occupies a distinctive place in the medical field. The contents of the pharmacopoeia have always represented a selection of those therapeutically active agents which, in the judgment of the revision committee, were the most important of the decade in which the Pharmacopoeia was issued. It also recognized such other substances as might be needed to standardize or from which to prepare these selected medicines.

The Pharmacopoeia also restricted most of its therapeutic agents to "simples" rather than to combinations of these on the theory that a physician should write a prescription for each patient, combining the medicines, whether chemical or other substances, in the proportion and with the vehicle which he believed best suited to that particular patient.

The National Formulary, on the other hand, admitted and standardized other medicines which were sometimes used by physicians but which were not believed to be of sufficient importance or suitable for admission to the U. S. P. The N. F. also admitted some preparations of U. S. P. simples in the form of solutions or combinations, already prepared and suitable for the physician to prescribe without devising his own prescription. The N. F. also contained many older drugs and preparations for which there was some demand and a few new preparations which had not yet been sufficiently proven to receive pharmacopoeial acceptance.

These two books, through their combined policies, are expected to include and standardize the medicines which are most frequently prescribed by physicians within the United States, but as they cannot give recognition to patented or trade-marked medicines, or those which are secret, there are many other medicinal products sold within the United States under private brands for which there is no official standard. However, under the Food and Drugs Acts, these unofficial products must conform to the claims made for them by the manufacturer and, while this is frequently evaded by the omission from the label of any specific statement as to strength or purity, the law operates effectively in some instances, especially when the product is a pill or tablet of an official substance and its strength must, of necessity, be given.

Another present-day publication should also be mentioned, although it is not an official publication and its standards are not enforceable under the Food and Drugs Act. This is the "New and Nonofficial Remedies" of the American Medical Association.

This book lists mostly proprietary medicines, but only those which comply with rigidly established rules which are enforced by the council on pharmacy and chemistry of the American Medical Association. These rules require the elimination of all secrets as to identity and composition. They also regulate the type of advertising which may be used for nonprofessional publicity. All false or misleading claims must be avoided and the title must be acceptable to the council and must not suggest its use in treating disease through self-medication.

The force of this publication resides in the desire of the owner of the product to occupy a favorable position before the physicians of the country and in this respect it has rendered an important service to the medical world through the maintaining of high standards of purity and promotion for many medicines which could not be controlled by the Food and Drugs Act under the U. S. P. or N. F.

Still another publication should be given recognition in the field of medical standards. This is the Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists. This is a compilation of standards and analytical methods published by the A. O. A. C. and accredited by the Secretary of Agriculture of the United States for use in the enforcement of food and drug standards in actions before the courts. The methods for testing were primarily for food, but methods for testing unofficial drugs and preparations, especially tablets, have been added and thus establish an additional basis for the standardization of modern medicines.

THE INTERNATIONAL STANDARDS

An explanation of the observations of the so-called Brussels Conference has already been made. This first met in 1902 and a second session in 1925. The international character of this conference is indicated by the fact that in 1925 the representatives of 32 nations participated. As has been explained, the Brussels Conference agreed upon uniformity in standards for potent medicines, also upon the parts and varieties of the drugs to be used and established international titles. These recommendations were left to voluntary adoption by the participating nations in their forthcoming standards. Needless to say, they have been widely accepted.

A new step in international standardization was brought about through the establishment of a Health Organization as a division of the League of Nations. This group has been particularly interested in the establishment of international standards for a class of medicines which are evaluated by testing on animals. It has undertaken the distribution of these throughout the world as a basis for uniformity in standards. In the biological division of the organization, international standards have been set up for digitalis and posterior pituitary and also for the unit value for vitamins A and D, for vitamin B^1 and for vitamin C and for the oestrus-producing or ovarian hormone.

International standards have also been adopted for some of the biologicals including diphtheria antitoxin and tetanus antitoxin and also for arsphenamine and insulin. This international service is being utilized by the pharmacopoeias of the world in the establishment of a uniformity in potency for these very important medicines.

PROPOSED SECRETARYSHIP ON PHARMACOPOEIAS FOR THE LEAGUE OF NATIONS

The latest move for international agreement on pharmacopoeial standards is an outgrowth of the last Brussel's Conference. This is the proposal that there shall be established as a division of the Health Organization of the League of Nations an office under the supervision of an international secretary for pharmacopoeias under whose direction there can be assembled for the benefit of all nations the scientific facts which have a bearing upon the standardization of medicinal substances. At the present time each national pharmacopoeial commission is compelled to assemble this information independently and of necessity with a varying degree of completeness. If this were done for all the nations of the world through this international organization, such a compilation of literature and experimental data could be issued to the participating nations in the language which they could use, and thus another workable phase of international cooperation would be established, contributing to the general health of all nations.

THE HEALING PROPERTIES OF ALLANTOIN AND UREA DISCOVERED THROUGH THE USE OF MAGGOTS IN HUMAN WOUNDS[1]

By William Robinson

A few years ago Dr. William S. Baer (1929) presented a new and unusual treatment of slow-healing wounds such as the persistent and widespread bone disease known as osteomyelitis. Sterile blowfly maggots were placed directly into wounds that had failed to heal under other treatments, and after a few applications of maggots the wounds in general became cleaner and healing began to take place.

In the early work of Dr. Baer and his associates, Dr. F. C. Bishopp, of the Bureau of Entomology and Plant Quarantine, was called upon to aid in the development of methods of producing surgically sterile maggots in ample quantity for the surgeon's use. From this early beginning entomologists have continued investigational work in this field.

The present report is a popular review of the subject to date. The original articles describing in detail the nature of the research and the results obtained have been published chiefly in medical journals listed at the end of the paper.

The Baer maggot treatment attracted considerable attention, and spread rapidly throughout the United States and into Mexico, South America, Europe, South Africa, and Australia.

Such a novel method as this aroused a good deal of interest in the manner in which maggots could produce beneficial results in stubborn discharging wounds. In nature the maggots feed upon dead and decaying animal material, and this loathsome habit naturally suggested that in wounds the maggots remove necrotic tissue and pus. Robinson and Norwood (1933) found further that the maggots are able to digest and destroy pus-forming bacteria. These habits would account for the cleaner condition of the wound and thereby make it more favorable for healing. The progress of healing in resistant cases of long standing was sometimes outstanding, however, and indicated that the maggots were not only acting as scavengers but were actually injecting a potent healing substance into the wound.

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[1] Contribution from the Division of Insects Affecting Man and Animals, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

A search for this healing agent was therefore attempted. On the one hand was the interesting phenomenon of blowfly maggots apparently producing something that stimulates healing in human wounds. On the other hand was the biological certainty that maggots would not do this merely to benefit their host. Throughout all nature no organism does anything primarily to benefit an unrelated individual. Any good effect arising from the association must be the result of a secondary or involuntary act. In the case of maggots this would include the function of excretion. As the fecal and urinary products of maggots are abundant and conspicuous, a study of them was undertaken first.

By means of a simple correlation the problem became further clarified. In the first place, it was commonly known that the application of macerated embryonic tissues to nonhealing wounds has frequently hastened healing; and the presence of allantoic fluid in the embryos suggested the main constituent, allantoin.

It was also known that in the urine of many mammals allantoin is present. True it had not been reported in insects, but uric acid, from which allantoin is oxidized, is conspicuously present. With these facts as a basis a search was made for allantoin in the excretions of blowfly maggots.

By the following procedure maggot excretions were readily obtained in sufficient quantity to permit identification of allantoin: Several thousand nearly full-grown maggots were reared under both aseptic and nonsterile conditions. They were placed in glass funnels which were stoppered with cotton and half filled with small glass beads to prevent overcrowding of the maggots. The maggots were occasionally sprayed lightly with water from an atomizer to facilitate drainage. The excretions were allowed to drip into beakers for 3 to 4 hours. With sterile maggots aseptic technique had to be used throughout the collecting process. A chemical analysis of the liquid showed allantoin to be present. From 20 cc lots of both sterile and nonsterile liquid, allantoin was separated in the crystalline condition, purified, and finally identified by comparison of its melting point and its optical crystallographic properties with those of an authentic sample.[2]

Interest was added to the investigation by finding about this time an article by Macalister (1912) written 22 years previously in England, stating that he had used allantoin successfully in the treatment of chronic ulcers. He had obtained it from the roots of a plant called comfrey. The original discovery of the healing properties of allantoin by Macalister met with little response at that time, and, unfortunately, was soon forgotten.

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[2] The isolation and identification of allantoin in these experiments were performed by Dr. E. P. Clark, of the Division of Insecticide Investigations of the Bureau of Entomology and Plant Quarantine, and Dr. G. L. Keenan, of the Food and Drug Administration, U. S. Department of Agriculture.

The amount of allantoin in maggot excretions is too small and the process of extraction too involved to make its use practical. Moreover, there is the natural dislike of a drug obtained that way. Fortunately, pure allantoin prepared synthetically for academic purposes was available in the United States. It is very slightly and slowly soluble in water, 0.6 percent being saturation. In these experiments a 0.5 percent solution was used.

In cooperation with hospitals in Washington, New York, and Pittsburgh, the effect of allantoin in stimulating healing was carefully tested. It was applied on gauze dressings thoroughly wetted with the solution and renewed daily. The types of wounds treated were chronic varicose ulcers, chronic osteomyelitis, and nonhealing heat burns. After a few daily applications it became evident that allantoin was bringing about an improvement in the wound similar to that produced by maggots. The odor was reduced, the wound became cleaner, and small areas of normal pinkish granulation tissue could be seen growing in the wound. This was followed in most cases by a general development of such granulation tissue.

The method of preparing allantoin solution for use was to heat a liter of sterile water to near the boiling point, then to add 5 grams of allantoin crystals and gently heat without boiling until all the crystals were dissolved. The preparation of a water solution should be done with reasonably aseptic precautions, as the solution cannot be autoclaved or boiled. Most commercial brands of the solution now contain a disinfectant. Allantoin is stable, mild, and soothing, and the solution has no taste or odor.

Allantoin is a substance occurring naturally in animal tissues, and it is also widely distributed among plants. It is a metabolic product and generally regarded as waste material. When the nucleus of the cell breaks down it yields nucleic acid, and gradually through a process of simplification uric acid is produced. Man and the manlike apes are unable to split uric acid any further, and it is, therefore, excreted in the urine in that form. Strangely enough, other mammals have in their tissues an enzyme called uricase, which oxidizes uric acid one step further, and the result is the formation of allantoin, a stable end product of metabolism. Many kinds of plants produce allantoin in various parts of their structure.

After a considerable number of chronic purulent cases had been treated successfully and with no evidence of irritation or other harmful effects, a preliminary report was published in the Journal of Bone and Joint Surgery in April 1935 (Robinson, 1935). This was done to acquaint medical readers of our findings and to enlarge the scope of the clinical tests. The result of this report, however, was altogether unexpected. Newspapers and journals took the story and at intervals throughout the following year published accounts of it in their pages.

This led to waves of publicity on the healing properties of allantoin and aroused a vast amount of interest in the subject. As a consequence a large number of physicians and surgeons obtained allantoin and used it clinically. At the same time many inquiries came in from people who wanted to treat themselves.

Thus from a beginning in which only a few cases of burns and ulcers were treated experimentally, the use of allantoin became extended to include treatment by the medical profession of purulent infections of the eye, middle ear, nose, and mouth, chronic osteomyelitis of all bones, eczema, severe sunburn, pruritis, diabetic and varicose ulcers, and suppurating heat and X-ray burns.

To illustrate further the remarkable healing properties of allantoin, without going into too much detail, but to show the wide range of wounds which respond to the treatment, a few typical cases are described from information supplied by our medical cooperators.

An elderly woman had an infected eye removed, and despite every treatment to reduce the infection of the eye socket it failed to heal and continued to discharge for 2 years. Finally, when the socket was packed with wet allantoin dressings it responded promptly and healed in less than 3 weeks.

Following extraction of a diseased molar tooth in a man, the jawbone became infected. Two operations for removal of dead bone and subsequent treatment for 9 months failed to check the discharge and bring about healing. Allantoin solution was then used and brought about a cessation of the purulent discharge and complete healing in 2 months.

Diabetic ulcers of the foot are very unpleasant and difficult conditions to treat, especially when the patient has to continue actively on his feet. Such ulcers frequently resist healing despite the best of treatment. With such a background of failure to heal, an application of allantoin ointment inside a protective pad enabled a patient to be treated without going to bed and resulted in satisfactory healing.

A man with chronic discharging X-ray burns of the foot had tried many kinds of treatment without avail, and for several years walked with the aid of crutches. After using allantoin solution for 2 months, he was so far recovered that he discarded crutches and used only a cane. Further treatment during the next few months enabled him to walk normally without support.

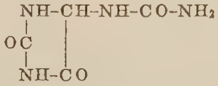
Following an operation for removal of a kidney from a woman, the incision, which had partially healed, broke down with considerable discharge, odor, and pain, and remained resistant to all types of treatment for 3 weeks. Daily packing of the wound with allantoin solution brought about considerable relief and complete healing within 10 days.

It is now nearly 4 years since allantoin was first used clinically in the United States. In that time no report appears to have been made of any harmful effect being found. A few published reports of results are beginning to appear in the medical literature (Greenbaum, 1936; Kaplan, 1937; Nicholl, 1937; Rice, 1936; Sussman, 1937).

The publicity that was given so frequently by the press to the discovery of the healing properties of allantoin interested not only the medical profession and the laity in its use but also a number of chemical and pharmaceutical concerns in its production. Within a few months allantoin was offered to the medical profession in crystalline form, in solution, in ointment, and in surgical jelly preparations, and it is now being sold in tablet form with okra for the treatment of stomach ulcers. In the ointment and jelly preparations allantoin must be dissolved and concentrated in hot water and then incorporated with the other materials which make up the base. Greenbaum (1936) describes the process in detail. An ointment made merely by adding pulverized allantoin crystals to an ointment base already prepared was once placed on the market for a short time. Such mixtures are ineffective, especially when a greasy base is used, because of the insolubility of allantoin except in hot water. Through the enterprise of pharmaceutical industries there is now no difficulty in obtaining allantoin products in any part of the United States. Over 80 allantoin preparations have been advertised for medical use.

The amount of allantoin being used medicinally in its various preparations is rather surprising. According to authentic sales reports, about 300,000 grams of synthetic allantoin crystals are now being produced annually. This amount would make over 140,000 pints of 0.4 percent solution, the usual concentration used clinically, or over 500,000 ounces of 2-percent ointment. It remains to be seen whether the popularity of allantoin will continue or whether it will suffer the fate of many other new drugs and eventually fall into disuse. At any rate, the present response to its discovery in maggot secretions is in strong contrast to the reception given to its previous discovery by Macalister in the roots of comfrey.

The effectiveness of allantoin in stimulating healing, now being established, led to the possibility that other substances with therapeutic properties might also be found in maggot excretions. The graphic chemical formula for allantoin is:



$$\begin{array}{l} \;\;\text{NH-CH-NH-CO-NH}_2 \\ \;\;\;| \qquad | \\ \text{OC} \quad\; | \\ \;\;\;| \qquad | \\ \;\;\text{NH-CO} \end{array}$$

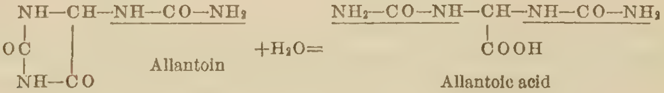
The side chain NH–CO–NH_2 upon hydrolysis through the addition of H from water easily forms urea, NH_2–CO–NH_2. Urea is present in maggot excretions and was therefore considered as a possible healing substance.

According to Marshall and Davis (1914) and Fearon (1926) urea is present in all organs and tissues of the body. In the blood and lymph its concentration is usually between 0.02 and 0.03 percent. The common occurrence of urea in the tissues and the harmlessness of it made it another interesting substance for experimental study. Through the interest and cooperation of a number of physicians and surgeons a weak solution (1 percent) of urea in water was given preliminary clinical tests. This concentration was later changed to 2 percent. The same types of chronic discharging wounds were treated as with allantoin.

After a number of applications it became apparent that, like allantoin, urea possesses remarkable healing characteristics. The odor of the wounds was decreased, they became cleaner, and healing proceeded promptly. In order that the urea treatment might be given more extensive tests, the number of our medical cooperators was considerably increased. The treatment was applied by them to a great variety of chronic nonhealing conditions, and the beneficial results appeared to be somewhat similar to those obtained with allantoin.

Beyond the fact that allantoin and urea have healing qualities apparently similar in their action, it has not been shown that the effect of allantoin is due to the hydrolysis of its side chain to form urea. That conception merely initiated an investigation on urea. Allantoin may bring about its effects through a different set of reactions.

One of the reactions of allantoin, however, is its hydration by an enzyme called allantoinase. This enzyme was discovered and named by Fosse and Brunel (1929) in the soybean and later found in a variety of plant and animal tissues, including some insects. Allantoinase reacts upon allantoin by the addition of 1 molecule of water to form allantoic acid, as follows:



Strangely enough, whereas allantoin has one side chain NH—CO—NH_2 allantoic acid has two. Allantoinase is not known to occur in mammalian tissues.

The usual conception as to the occurrence of urea in the animal body appears to be that it is a waste product only and an efficient means of eliminating excess nitrogen. Owing to this deeply rooted belief, it has been, and still is, difficult for intellectual and scientific persons to grasp the fact that urea is not merely a waste product. The peasantry of Europe and similar classes throughout the world have for ages availed themselves of the healing properties of urine, and are today still using urine on wounds for that purpose. Frequently in the folklore and sometimes in essays and historical writings references have been made to this practice. Such statements have been traced through medieval times back to the writings of Cato, 175 B. C. Records have been found tending to show that even the ancient Babylonians, about 800 B. C., indulged in the same practice. Since the main constitutent of urine, next to water, is urea, in about 2 percent concentration, this ancient remedy for nonhealing wounds now appears to be basically sound.

The method of applying the urea treatment in our experimental work was on gauze dressings thoroughly wetted with 2 percent solution, the same as in the allantoin treatment. Urea is a stable, bland, and nontoxic substance, and no report of any ill effect from the treatment has been received. It is very soluble in water and a concentration as high as 40 percent is possible. Many kinds of bacteria contain an enzyme called urease, which breaks down urea and releases ammonia. For that reason sterile water should be used if the solution is to be kept for some time.

A report published in the American Journal of Surgery, August 1936 (Robinson, 1936), on the remarkable healing properties of such a common excretory substance as urea again interested many of the newspapers and journals in the United States, and once more a considerable amount of publicity was given to these experiments. The result was a wide trial of urea by the medical profession and, happily, with confirmation of our results. An article by Bogart (1937) on his successful use of urea has already appeared in the medical press. He refers to the outstanding healing effects he obtained when other methods had failed, and concludes as follows: "It seems reasonable to assume that a new and very potent factor in the healing of indolent wounds has been added to the armamentarium of the surgeon." Still more recently Lewy (1937) has reported beneficial results with 2 percent urea solution in the treatment of infected conditions of the nose, ear, and throat.

Nevertheless, a certain amount of skepticism naturally exists that urea has such healing properties as described. Holder and MacKay (1937) suggest that we are mistaken in attributing healing characteristics to urea. They obtained good results with strong urea solutions but believe it to be due solely to the solvent and bacteriostatic action of strong urea.

The tendency to doubt that urea has healing powers and the neglect of this potent agent, despite the extensive background of usage in urine, become still more pronounced when contrasted with the general acceptance of its numerous and remarkable uses in industry and pharmacy, as described by Berliner (1936). This skepticism and neglect are no doubt due to the long association of urea with animal excretions. Urea is, however, of common occurrence in plants, some of which are used as food. Fourcroy and Vauquelin (1798), who discovered urea, found it first in urine and unfortunately called it "urée." The stigma attached to urea could possibly be removed through a fuller knowledge of its chemistry and its remarkable position in physiology and industry.

Urea was the first organic substance ever to be produced artificially. This historic achievement by Wöhler (1828), over a century ago, was a discovery of far-reaching importance. It opened the way to the preparation of other organic substances the number of which has now grown to an enormous extent. It also shattered the belief commonly held at that time that organic substances are the result of a mysterious vital force which could not be duplicated in the laboratory. Werner (1923) said that if the amount of study devoted to the chemistry of a subject is any indication of its importance, then urea must take a high place in that regard.

Under the present circumstances, since urea is now being used clinically, it might be well to remember that the urea of commerce and pharmacy is a manufactured product made by combining two synthetic gases, ammonia and carbon dioxide, to form urea, $CO(NH_2)_2$, a pure crystalline product. Chemically pure urea made by this process is now being produced commercially in the United States, and thousands of tons are used annually. Its cheapness is greatly in its favor for extensive clinical use. It can be purchased at this time in 1-pound bottles at 50 cents and in 20-pound containers at 18 cents a pound. In 100-pound moisture-proof sacks the price is reduced to the extremely low figure of 5 cents a pound. In concentrations of 2 to 10 percent the cost of daily applications to each patient is, therefore, so slight as to be almost negligible. Bogart (1937) has used it in strong solution, and even in crystalline form in some very resistant cases, with good results. Even in these concentrations the cost of daily treatments is exceedingly slight.

Owing to the low price of commercial urea, it appears to be practical to make up a dilute solution of it in a bathtub (Robinson, 1936) for treatment of cases of extensive secondary infections of the skin following an injury by poisonous plants, insect attack, heat burns, or sunburn. Extensive applications of this sort have already been made on a small scale with good results in the treatment of certain generalized skin conditions. As there is a wide range in the concentration of urea that can be used effectively, no exact amount appears to be necessary when making up a solution in a tub. Two double handfuls of the crystals have been found to make a satisfactory concentration. It should be remembered that when urea is added to water the temperature is lowered somewhat.

Urea in amounts up to 10 or 15 percent can be incorporated with ointment or jelly bases with great ease. It is merely added to the bases and thoroughly mixed. It goes at once into solution in the water that is present.

Despite the cheapness of urea and the ease with which it can be made into a pharmaceutical product, it is still unpopular. At the present time only four urea preparations are known to have been made.

Both allantoin and urea when undissolved are white in color and crystalline in form. In solution they are colorless and odorless. Allantoin, having no taste, is especially acceptable for treatment in the mouth and is now being used extensively for that purpose. Sussman (1937) has recently published a series of case histories on the successful use of allantoin in the treatment of resistant infections of the mouth. Weak solutions of urea, from 1 to 2 percent, have only a mildly unpleasant taste, not enough to make them unsuitable for oral use, and such solutions are giving excellent results. In some cases where the taste is objectionable a flavoring material is added.

Neither allantoin nor dilute urea has any direct bactericidal property; yet the bacterial count usually goes down in a purulent wound when either of these materials is applied. They have no proteolytic or dissolving action, but necrotic material in discharging wounds begins to disappear and the wound becomes cleaner under treatment. Such effects, therefore, cannot be attributed to any direct activity of these healing agents. It has been observed repeatedly, however, that they do stimulate growth of granulation tissue having an abundant blood supply. The probability is, therefore, that the cleansing of the wound is produced indirectly through the stimulation of an underlying growth of healthy granulation tissue.

The fate of a new drug is typically uncertain. Sometimes its merits are overemphasized and early reports of good results cannot be duplicated. Not fulfilling expectations, it frequently falls into disrepute. It was this that led a professor of pharmacology to say to his students: "Gentlemen, make haste to use a drug while it is new."

The truth cannot be avoided that allantoin once fell by the wayside. This was not because of disappointment in results but through neglect. With its merits still untested except by Macalister and his associates, it became forgotten. No use appears to have been made of its healing powers in the World War which began 2 years later; and no mention of it has been found in any works on pharmacology, therapeutics, or pathology. Strangely enough, the reappearance of allantoin as a therapeutic substance has been in strong contrast to its original discovery. This time, being accompanied by an unusual amount of publicity, the opportunity to test it thoroughly has been possible.

Urea, however, is in a class by itself for large-scale treatments, either civilian or military. Its cheapness, its availability in ton lots if desired, the ease with which it goes into solution, its harmlessness even in strong concentrations, and its effectiveness in stimulating healing make urea an unusually interesting therapeutic agent. One might conjecture what its effect might have been had it been used during the World War. If allantoin sales do begin to diminish, one need not look far for a cause—the qualities of its extraordinary chemical associate, urea

REFERENCES

Baer, W. S.

1929. The use of a viable antiseptic in the treatment of osteomyelitis. South. Med. Journ., vol. 22, pp. 582–583.

Berliner, J. F. T.

1936. Crystal urea. Its industrial uses. Chem. Indus., vol. 38, pp. 237–242.

Bogart, L. M.

1937. Urea. Its use in infections. Journ. Mich. State Med. Soc., vol. 36, pp. 285–287.

Cato, Marcus Porcius

234–249 B. C. De re rustica. (English translation by Hooper and Ash. Harvard Univ. Press, Cambridge, 1934.)

Fearon, W. R.

1926. The biochemistry of urea. Physiol. Rev., vol. 6, pp. 399–439.

Fosse, R., and Brunel, A.

1929. Un nouveau ferment. Compt. Rend. Acad. Sci. [Paris], vol. 188, pp. 426–428.

Fourcroy and Vauquelìn

1798. L'Histoire naturelle chimique et médicale de l'urine humaine, contenant quelques faits nouveaux sur son analyse et sur son altération spontanée. Ann. Chim., vol. 31, pp. 48–71.

Greenbaum, F. R.

1936. Allantoin, a new granulation tissue stimulating substance with especial emphasis on allantoin in ointment form. Amer. Journ. Surg., vol. 34 [n. s.], pp. 259–265.

Holder, H. G., and McKay, E. M.

1937. The use of urea in the treatment of infected wounds. Journ. Amer. Med. Assoc., vol. 108, pp. 1167–1169.

Kaplan, T.

1937. The allantoin treatment of ulcers. Journ. Amer. Med. Assoc., vol. 108, pp. 968–969.

Lewy, R. B.

1937. Use of urea in disease of the ear, nose, and throat. Arch. Otolaryngology, vol. 26, 195–199.

Macalister, C. J.

1912. A new cell proliferant. Its clinical application in the treatment of ulcers. Brit. Med. Journ., vol. 1, pp. 10–12.

Marshall, E. K., and Davis, D. M.

1914. Urea. Its distribution in and elimination from the body. Journ. Biol. Chem., vol. 18, pp. 53–80.

Nicholl, R. G.

1937. Maggot therapy and allantoin. Journ. Amer. Osteopath. Assoc., vol. 36, pp. 345–346.

Rice, E. C.

1936. Diabetic ulcers and their treatment in podiatry, with special reference to use of allantoin and 2% urea. Journ. Nat. Assoc. Chirop., vol. 26, pp. 1–2, 30–32.

Robinson, W.

1935. Stimulation of healing in nonhealing wounds by allantoin occurring in maggot secretions and of wide biological distribution. Journ. Bone and Joint Surg., vol. 17, pp. 267–271.

1936. Use of urea to stimulate healing in chronic purulent wounds. Amer. Journ. Surg., vol. 33 [n. s.], pp. 192–197.

Robinson, W., and Norwood, V. H.

1933. The role of surgical maggots in the disinfection of osteomyelitis and other infected wounds. Journ. Bone and Joint Surg., vol. 15, pp. 409–412.

Sussman, S.

1937. Allantoin. Dental Items of Interest, June 1937.

Werner, E. A.

1923. The chemistry of urea, the theory of its constitution, and of the origin and mode of its formation in living organisms. *In* Monographs on Biochemistry. 212 pp. London.

Wöhler, F.

1828. La formation artificielle de l'urée. Ann. Chim. et Phys., vol. 37, pp. 330–334.

THE AIMS OF THE PUBLIC HEALTH SERVICE [1]

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It is a signal honor for any member of my profession to be honored by this venerable and vigorous institution of learning. I accept this degree with profound gratitude and appreciation, recognizing that it is less of a personal tribute than it is a recognition of the growing importance of the specialty which I represent.

Like the Philadelphia College of Pharmacy whose one hundred and sixteenth anniversary we are celebrating today, the Public Health Service had its birth here in Philadelphia. It was in 1798 when John Adams was President, that Congress passed "an act for the relief of sick and disabled seamen." Under its provisions a deduction of 20 cents per month was made from the wages of each seaman on the merchant ships of the United States. The funds were deposited with the collector of customs in a marine hospital fund and used to build and operate a series of hospitals in the principal ports.

This was the beginning of a Federal medical service, and, incidentally, the first health insurance system. In the latter connection it is interesting to note that after operating for nearly a hundred years as a contributory scheme, financed by employee contributions through a pay-roll check-off, it was replaced by a tonnage tax on the ships, viz, employer payments, and later supported by general taxation, viz, State medicine. The terms "health insurance" and "State medicine" had not yet been coined. In fact they now connote new and radical departures in medical practice, yet since 1798 we have had one or the other form of socialized medicine for this one group of wage earners. From this disconnected system of marine hospitals, a national Marine Hospital Service grew. The doctors in these hospitals frequently were the first to diagnose and treat exotic diseases. Because of this they were consulted by local health authorities when yellow fever or cholera threatened. The earlier system of State-operated quarantine stations lacked uniformity, and by 1893, it became obvious that this should be a Federal function.

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[1] An address delivered at the Philadelphia College of Pharmacy and Science, Philadelphia, Pa., Founder's Day, February 23, 1937. Reprinted by permission from the American Journal of Pharmacy, March 1937.

Because public health itself is a new concept, it was not until 1908 that the name "Public Health" was added to this 100-year-old service. Since then progress has been rapid in developing an organization which in fact as well as in name is a Federal Public Health Service.

On an occasion such as this, one is tempted to review and appraise the significant events in the long and distinguished history of the organization which I have the honor to direct. One could properly dwell with pride over the pioneer studies of Henry R. Carter in yellow fever which paved the way for Walter Reed's discovery of mosquito transmission; or the epochal work of Joseph Goldberger in establishing the nutritional nature of pellagra; or the unique contribution of Edward Francis in tularemia (he is the only American who has discovered a disease, found the cause, method of transmission, insect vector, and animal host); or the recent alum-picric acid spray of Charles Armstrong, which prevents poliomyelitis in monkeys and offers so much hope in man; or the courageousness of Spencer and his co-workers in their successful search for a vaccine to prevent Rocky Mountain spotted fever. They and others in the Public Health Service have contributed much to scientific knowledge of disease prevention.

Progress is being made in the control of the venereal diseases. By one laborious step after another, we are extending our knowledge of mental illness, and of cancer. Since 1880, we have been working out the most satisfactory basis for cooperation with States in providing better health services for the people. As a result, prompt effect has been given to the health provisions of the Social Security Act under which $8,000,000 is being granted to the States for public health work. The mobilization of forces to combat the threat of epidemics in the wake of recent floods gives another illustration of the success of modern public health effort.

Appropriate as it might be to dwell upon any one of these events in the history of the Public Health Service, the title of my paper and my own inclinations impel me to consider what is ahead; to discuss the aims in view and the methods by which these aims may become actualities.

I shall pause only to review briefly the scientific, social, and economic bases upon which our health activities rest, for as stated in the preface of the centennial volume of this college, "The history of yesterday foreshadows the experience of today and tomorrow."

During the past century the spirit of inquiry in medicine has replaced dogma and tradition. The studies of Pasteur, Lister, and the host of other scientists have transformed medicine no less than has the power of steam transformed industry. A generation ago a doctor with his saddlebags could encompass most of the then available medical knowledge. Not so now, when it is a life's work to master just one specialty.

This growth of scientific knowledge has multiplied the number of things which can be done to prevent and cure disease. It also has increased the cost of medical service, putting such service beyond the reach of an increasing number of people. Moreover, our transfer from an agrarian to an industrial system, with workers dependent upon a daily wage sufficient only to meet current necessary living costs, has resulted in the inability of many citizens to buy medical care when the wages stop.

Changing social concepts also supply an additional basis for public health work. The growth in the sentiment against suffering has been more rapid during the past century than ever before in the world's history. The abolition of slave trade, the growth of popular education, and the development of measures of public assistance are examples.

Modern society everywhere accepts as an obligation the provision of the necessities of life for those who cannot provide such necessities for themselves. Since medical service is a necessity of life, it is only a small step to acceptance of the principle that such service must be made available by the community for those in need.

There are cogent economic reasons also for health services. A sick individual may become a burden upon society. Good health is an important factor in human efficiency. The treatment of disease is no longer a concern solely of the individual who is sick. The community as a whole has a financial stake in untreated illness. This point has become clear in recent years as we have accepted as a nation responsibility for providing pensions to the dependent groups of the population.

There are sound scientific, social, and economic reasons for more aggressive attention to the public health. I think we have reached a stage in our civilization when we must accept as a major premise that citizens should have an equal opportunity for health as an inherent right coequal with the right to liberty and the pursuit of happiness. To realize this ideal is a broad aim of the Public Health Service. The methods we use fall into two major divisions, first, the better application of scientific knowledge for the prevention and cure of disease, and second, the acquisition of new knowledge.

Within the past 2 years, a good start has been made in the development of a national health program. In the Social Security Act for the first time, the Federal Government declared a continuing policy of assisting States and localities in providing better health service. It has been relatively easy to inaugurate this work because since 1880, the Public Health Service has been authorized to cooperate with States in the prevention and control of disease. It has been possible to work out health programs in every State so that the States retain a full measure of responsibility for their own health programs subject only to meeting minimum standards which have been agreed upon jointly by the State health officers and the Public Health Service. The $13,200,000 being granted by the Public Health Service and the Children's Bureau is producing significant results in better health for the people. This appropriation, however, represents only about 10 percent of the total cost of public health work. The recent national conference on venereal disease control called attention to the need of greater Federal interest in the control of these and other diseases. At this conference, it was earnestly recommended to the administration that authorization for $25,000,000 be given in appropriate amendments to the Social Security Act, to be administered by the Public Health Service. It was also the opinion of this conference that the percentage of Federal money invested in the prevention of disease should not be less than the percentage invested in the care of dependents.

We must narrow the gap between what we know and what we do in public health. There are major causes of disease and death in regard to which present community action is totally inadequate.

The control of syphilis is a notable example. With the recent great increase in public interest in this subject, it should be possible to make this a rare disease within our generation. Medical and public health officials are agreed as to the methods. The recent conference drew a series of blue prints which every State and every community can follow.

Cancer stands second among the causes of death. The cause of cancer is not yet known, but many cases of cancer can be cured by many known methods. Experts in this field estimate that 25 percent of cancer deaths could be prevented if all of our knowledge of cancer control was used. Two States have accepted some measure of responsibility for the treatment and cure of cancer through providing public facilities for those in need of care.

Pneumonia ranks high among the causes of death, but recent scientific advances point the way to preventing many such deaths. For several of the most frequent types of pneumonia, an improved concentrated serum has been developed which is quite effective. Moreover, a rapid method of typing the disease makes it possible for those cases to be located promptly which are amenable to serum therapy.

The control of tuberculosis is a job half done. This disease has been reduced by two-thirds in the present century. We have now reached a point where we can look forward to the practical eradication of tuberculosis.

The medical care now being furnished to the dependent groups of the population is poorly organized and inadequate. There must be general acceptance of the principle that the medical care of such dependents is a public responsibility.

Facilities for diagnosis and treatment of diseases frequently are lacking particularly in the rural areas. We need a great extension of laboratory service, the provision of hospitals particularly in rural areas, better organized dispensary services, and a better integration of private and public effort in the prevention and treatment of disease. As a nation, we should seek not only to make medical care more available to those in need of such care, but constantly to seek the improvement in the quality of medical service.

The Public Health Service itself will play a relatively small part in the health advancement of the future. It should be in a position, however, to promote, assist, and advise in the working out of State and local health programs. I am less interested in the size of the organization I represent than in the brains it represents. For many years, we have given an opportunity for a career service. We need to attract the best of the medical graduates, to give them every opportunity for professional advancement, to train specialists in all phases of our work. I dream of a day when the Public Health Service will have a corps of men and women whose ability is not surpassed or equalled by any other medical or health organization in the world.

I have referred briefly to some of the research work of the Public Health Service. Plans are being drawn for a new National Institute of Health to be located in the environs of Washington, the headquarters for all of the research work of the Public Health Service. This should be more than a research institution. It should be also the headquarters for the training of our personnel. It should be the West Point of the Public Health Army.

The major unsolved problems of health and disease should be a concern of this institute. Scientific workers from other institutions will be free to bring their problems here and pursue their studies within its walls. Other scientists should go out from this institute to other institutions of the country. Such a constant interchange should promote progress. Many research problems of today are so complex that it is impossible for an individual worker and frequently it is impossible for any one organization to deal adequately with them.

The Federal Government is in a position to lend its influence in bringing together various scientists concerned with a common problem and promoting joint and coordinated attack. Already we can point to progress in this field of cooperative research. For 8 years, five of the leading syphilologists of the country have worked with the Public Health Service in pooling their knowledge, their material, and their resources for study of syphilis. Valuable additions to our knowledge have come as a result of these cooperative clinical studies.

The problem of drug addiction has been the subject of joint interest by the Public Health Service and the National Research Council.

One of the aims is to develop a synthetic drug which will have all of the virtues of morphine without its habit-forming qualities. A chemist at the University of Virginia has synthetized a number of compounds. These are being tested on animals at the University of Michigan and those which passed animal tests are being tried on patients in Massachusetts. Similar cooperative studies are under way in cancer. This principle can be applied to many problems. It is my hope that our Institute of Health will extend this principle widely. In addition, promising studies should be supported by grants-in-aid along the lines which have proven profitable in recent years.

SUMMARY

The aims of the Public Health Service are easily summarized. We seek to narrow the gap between what we know and what we do, and to extend the boundaries of knowledge of health and disease. We ourselves will play a small part compared with the total job to be done. We seek for ourselves not size but efficiency, not legal authority but the confidence of our colleagues and of the public we serve. We hope that our aims of today will be "the experience of tomorrow."

EXCAVATIONS AT CHANHU-DARO BY THE AMERICAN SCHOOL OF INDIC AND IRANIAN STUDIES AND THE MUSEUM OF FINE ARTS, BOSTON: SEASON 1935–36 [1]

By Ernest Mackay
Field Director

[With 10 plates]

The Museum of Fine Arts, Boston, now possesses a remarkable and widely representative collection of objects from the ancient Indus Valley, the only such collection outside India. Not only is the culture of Harappa and Mohenjo-daro well represented at Chanhu-daro in the Nawabshah District of Sind (fig. 1), the site at which this collection was unearthed, but there were also found the seal-amulets and pottery of a people who occupied the site fairly soon after it had been deserted by the Harappa people, objects which it will be seen differ radically from those left by their predecessors.

The mounds of Chanhu-daro were selected for the preliminary investigations of the first American archeological expedition to India on account of important finds made there during a survey of the ancient sites of Sind by the Archeological Department of the Government of India in the winter season 1929–30. Mr. N. G. Majumdar, who dug three trial trenches there, showed that Chanhu-daro had been occupied by the same race that built the cities of Mohenjo-daro and Harappa some 5,000 years ago. He also found some slight evidence of the presence of a later civilization which can now be named the "Jhukar culture", in accordance with the convenient practice in Egypt and Mesopotamia of naming a culture after the site where traces of it were first found. The so-called Indus Valley civilization should be renamed the "Harappa culture", for further excavations in the great river valley will undoubtedly reveal the remains of yet other ancient cultures.

Chanhu-daro is some 12 miles east of the present bed of the Indus, about 80 miles SSE. of Mohenjo-daro. Its three mounds comprise an area of 9 acres, but the little city was considerably more extensive in ancient times and the alluvium deposited in the course of 5,000 years or more now covers the lower parts of the mounds. Mound I is 22.2

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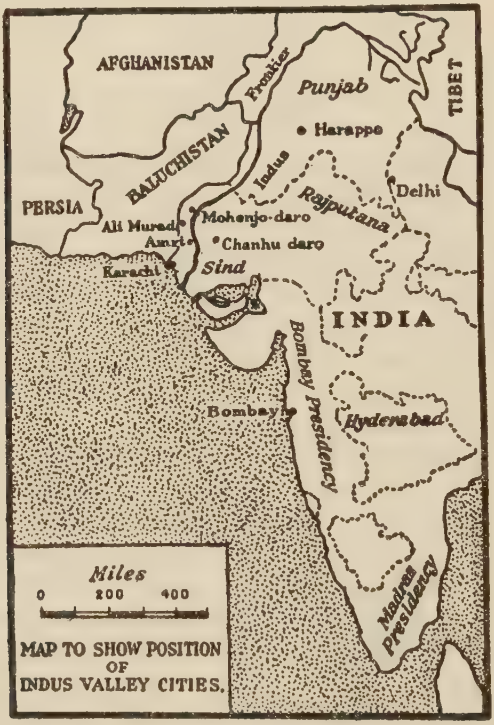
[1] Reprinted by permission from the Bulletin of the Museum of Fine Arts, vol. 34, no. 205, Boston, October 1936.

feet high, and some 1,500 square feet in area, and the rather larger Mound II, 23.5 feet high and about 3,850 square feet in extent, is separated from it to the NE. by a gap some 150 feet wide. (pl. 1) During the period of the Harappa culture, Mounds I and II were one, through which a devastating flood ultimately cut its way, bringing to a close the longest and most important chapter of the history of the little city. Mound II was reoccupied later for two brief periods, as we shall shortly see. The third mound (III), which stands a few feet high and is only some 500 square feet in extent, lies close to the NW. of Mound II, of which it is certain that it once formed a part; the rainstorms which have separated this little mound from its neighbor have left their marks as deep furrows and ravines which scar the sides of all three mounds.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BALUCHISTAN
Indus
Delhi
PERSIA
Ali Murad
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MAP TO SHOW POSITION OF INDUS VALLEY CITIES.

FIGURE 1.—Map of the Indus Valley.

As Mound II was the largest and highest mound and therefore likely to contain the most interesting material, it was selected for our principal excavations. Its upper portion was systematically removed, layer by layer, the debris being dumped on ground that had already been examined by means of trenching. On the summit of the mound were one or two graves of early Muhammedan date. Below these very late remains, a few pieces were found, mostly intact, of a very interesting dark gray, polished, hand-made ware with incised geometric decoration (pl. 2, fig. 1). The exact date of this ware is at present a matter of surmise, but in shape and technique it is entirely different from anything produced by the two cultures whose remains we found beneath it. I am inclined to think that this gray, hand-made pottery was made by a primitive people who were the last to occupy the site—and that only very briefly and in small numbers—and who may have been a race allied to the Bhils, of whom there is a settlement close to Chanhu-daro; these Bhils, however, have lost most of their ancient customs and primitive way of living.

In the stratum below this gray ware we came upon a large quantity of wheel-made pottery, quite unlike the wares found either above or below it. This pottery which was mostly polychrome, with devices painted in black and red on a cream or pink slip, is represented mainly by broken fragments of the pans and stems of offering-stands, though pieces of other types of vessels also were found (pl. 2, fig. 2). Though polychrome pottery was made at the latter end of the Harappa period, the polychrome ware of the upper levels of Chanhu-daro in nowise resembles it in shape or style of decoration. Its presence in considerable quantities therefore emphatically marks the occupation of the site by a different people. At Jhukar also, where Mr. Mazumdar first unearthed pottery of this kind, it was in a stratum that showed it to be of later date than the Harappa culture. A principal feature of this Jhukar ware is that broad horizontal bands of red separate the various devices that ornament it. Red was also used in combination with black for certain motifs, a common one being a chevron pattern of red and black alternately (pl. 2, fig. 3). The designs on the Jhukar pottery are either geometric or very conventionalized, boldly painted plant designs of leaves or buds joined together with curved stems. As a rule these plant designs were painted in black, or a deep purple, the red being used for the broad bands separating the registers, but occasionally the interiors of the buds or leaves, if not hatched (pl. 2, fig. 2), were colored red.

The only other known wares that the Jhukar pottery resembles—and only in the designs and use of colors, not in shape—are those found by Baron Max von Oppenheim at Tell Halaf in northern Assyria[2] and by M. E. L. Mallowan at Tell Chagar Bazar.[3] At both sites broad horizontal red bands were used to separate the registers, and the very distinctive chevron pattern in alternate red and black on a number of the Jhukar potsherds of Chanhu-daro is identical with the chevron design on the later Tell Halaf pottery. Other painted devices on these wares correspond very closely. Mr.

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[2] For a popular account see Baron Max von Oppenheim, Tell Halaf.

[3] Iraq., vol. 3, pt. 1, 1936.

Mallowan has postulated "a link which will bridge the gulf between the end of the Tell Halaf period and the pottery of India and Baluchistan," and he suggests that the early potters of Assyria and Syria moved eastward. There seems no doubt that the pottery of the Jhukar culture had been influenced by the later wares of the Tell Halaf culture, and we must look to the Iranian Highlands for the region whence it was brought to India. The fact that the Tell Halaf pottery is considerably earlier in date than the Jhukar ware is no matter for concern; some time had necessarily to elapse before an influence from Syria could have had effect in northwest India, and many long halts were doubtless made before the end of the journey. The people who introduced the Jhukar culture into the Indus valley appear to have left but few traces in Baluchistan; but a great deal of systematic excavation needs to be done in that country, for one notable sherd with red and black chevrons found by Sir Aurel Stein at Zayak might equally well have come from the Habur region or from India.[4] The presence on some of the pottery of ancient Baluchistan of wide red lines between the registers is a feature shared both with the north Mesopotamian pottery of Tell Halaf and the Jhukar ware of the Indus valley.

There is a considerable body of evidence that the people of this Jhukar culture occupied the principal mound at Chanhu-daro comparatively soon after its desertion by the people of the Harappa culture, and I would date this occupation to about 2000 B. C. It was only a small settlement and, judging from the number of rough pavements and fireplaces found, the people lived in houses of matting, all other traces of which had disappeared. The head-man had a plain, roughly built house of bricks, taken either from the lower part of the mound or from other buildings of the Harappa culture in the vicinity. One very interesting feature in a room of his house was a fireplace in a recess in the wall with three bricks still in it which served to support a cooking vessel (pl. 3, fig. 1).

Not only does their pottery, of which a surprising amount was made and used, distinguish these people from their predecessors of the Harappa culture, but they wore seal-amulets, mostly pottery, which in their shapes and ornamentation are totally unlike the square and rectangular seal-amulets of the Harappa culture. Some are round stamp seals with roughly shaped perforated handles at the back, and others lentoid with designs on both faces and perforated laterally (pl. 2, fig. 4). These Jhukar amulets are with one or two exceptions very roughly made, and none bears any inscription; in fact, we are as yet uncertain whether their owners knew how to write. Many of them resemble certain seal-amulets of early Elamite date, and one exceptionally well made lentoid amulet with an endless rope pattern on one side recalls both in shape and the design certain Hittite seals;

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[4] Gedrosia, p. 33, pl. 1, z. n. 7.

which is the less surprising when we consider the marked affinities of the pottery with the late ware of Tell Halaf.

A number of bone awls polished by much use suggests that the Jhukar people made baskets, and judging from the number of bobbin-shaped objects that they left they seem also to have been workers in textiles. The figurines of the Harappa levels tell us that the headdresses of that period were very elaborate, and this appears to have been the case in the Jhukar period also; a very fine headrest of painted pottery was undoubtedly intended to protect the headdress of its owner from damage during sleep.

Close beneath the Jhukar stratum we came upon buildings of the Harappa culture at a level approximately 13 feet below the summit of the mound. Here were found the remains of burnt brick houses with the bathrooms, drains, and other conveniences now well known at Mohenjo-daro and Harappa. Here, too, were found the copper and bronze implements and tools that now form an important part of the collection in the Museum. Two hoards of these implements were so corroded together that it was not until the end of the season when they could be chemically cleaned and separated that we became aware of what we had found (pl. 3, fig. 2). Blade axes (pl. 4, fig. 1), chisels, spear heads, and copper and bronze vessels of various shapes, all go to show that Chanhu-daro was a great center of metal working; but whether bronze or copper was the metal more commonly worked can only be ascertained by analysis of the material obtained.[5] Considerable skill in the working and casting of bronze is shown in the cosmetic jar (pl. 3, fig. 3), and especially in the toy cart with a pent roof. The latter shows us a type of vehicle that was in common use at the time, for a very similar little model has been found at Harappa, well over 400 miles away to the NE.[6]

Important evidence of metallurgical practice was the number of small masses of lead that were found, evidently the remains of some considerable working in this metal. These fragments of lead are now being examined for their silver content, but it may be that any silver that existed was extracted before the lead reached Chanhu-daro.

No skeletal remains of either the Jhukar people or Harappa people were found, save a skull that had been placed in a large storage jar together with a small collection of metal objects and a large conch shell. Some care must have been exercised in inserting this skull in the jar, whose opening was barely wide enough to receive it; and why the skull only was thus carefully preserved and not the other bones is a matter for speculation.

Bead making was practiced even more extensively at Chanhu-daro than metal working. The long agate and carnelian beads of barrel-cylinder shape, of which so many fine specimens were found at Mohenjo-daro, were quite possibly made at Chanhu-daro, for large numbers of them were unearthed in all the various stages of making. The long rectangular slips of stone struck from the parent nodule were first flaked roughly into shape, then, after careful chipping to remove the angles, they were ground into the required cylindrical form by rubbing on a piece of sandstone, which became deeply grooved in consequence. The beads were bored from both ends with a stone drill, and they finally received a polish that shows the craftsmen of Chanhu-daro to have had long experience in the art of working hard stones. The stone drills that were used, of which a number were found, both whole and broken, are a new discovery; it has hitherto been supposed that in ancient times stone beads were bored by means of a copper drill with the aid of an abrasive. These stone drills, of chert, must themselves have taken considerable time and labor to shape, and as their hardness is about the same as that of the stones used for bead making an abrasive must have been used with them; but whether the latter was emery or some other material we have yet to discover.

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[5] At Mohenjo-daro, bronze was nearly as common as copper, even in the lowest levels.

[6] Ann. Rept. Arch. Surv. India, 1926-27, pl. 23, d.

Beads were also made of softer materials such as steatite; a number of tubular shape, stuck together by the salty soil and evidently once contained in a fine basket which had perished, would, if placed together end to end, run 35 to 40 to the inch. How they were shaped and, even more, how they were bored is at present quite incomprehensible.

Save in their extraordinarily skillful bead-making and also in the manufacture of weights—a subsidiary industry—the people of Chanhu-daro made little use of stone for other purposes. Copper was evidently so plentiful that stone implements had already been practically discarded. Ribbon-flakes struck from a core of coarse chert were, however, doubtless used as kitchen knives: they were found in many of the houses, together with the cores from which they were struck, and it is evident that the housewife provided herself with simple knives as easily as she discarded them when blunt.

Stone was occasionally used for mace-heads, both of globular and lentoid shape, for drill-caps, and even for dishes; the latter, however, were both few in number and very clumsily made. They were, moreover, sometimes made of a soft form of alabaster, a stone which does not withstand corrosion by salt. A large number of rectangular stone palettes with smooth level surfaces were found, but the great majority were broken. They were probably used for preparing cosmetics and may have been placed on the small, roughly made pottery toilet tables with four short legs, which also were rarely found intact.

A remarkable number of toys were found at Chanhu-daro, far too many, it would appear, to have supplied the wants of the child population there; it is possible that toy-making also was a local industry. Toy vehicles of various shapes made of pottery, mounted on two or four wheels and drawn by a pair of humped oxen as in modern Sind, form an interesting feature of the collection in the Museum (pl. 5). Pottery model rams, with the fleece indicated by lines of red paint and mounted on two wheels with a hole through the neck for a draw-string, were common playthings. Marbles of pottery and stone, whistles ovoid or shaped like hens (pl. 4, fig. 2), and brightly colored rattles for the younger children were abundant. The better made playthings in the Museum collection are undoubtedly the work of professional toy makers; but the children also made toys for themselves in mud, and baked them in holes in the ground covered with fuel.

A number of pottery figurines were found of the Mother-goddess, who was also worshipped at other centers of the Harappa culture. Some of these figurines wear a curious fan-shaped headdress ornamented with bands of material, unless it is strands of hair that are represented, carried over a support of some kind. The nose was simply pinched up by finger and thumb, and in the depressions thus formed pellets of clay were set to represent the eyes. Possibly there was one of these little figures in every house in a niche in the wall; and with them there seem to have been associated the little model doves with outstretched wings, each with a hole in the base to set it on a wooden pin. As we know that the dove was intimately connected with the worship of the Mother-goddess in ancient Crete, Sardinia, Mesopotamia, and elsewhere, it seems likely that it was in the Indus valley also. These bird figures were most probably votive offerings, placed in or upon the shrine of the Great Mother in fulfillment of a vow or in the hope of favors to come.

The seals—or rather seal-amulets, for they undoubtedly served both purposes—were all made of steatite. In shape, material, and the animals engraved upon them, they are identical with those found at Mohenjo-daro and Harappa, and many of them were similarly given a smooth white surface to enhance their appearance. The animal most often represented on these seal-amulets is an oxlike beast always in profile with a single horn (pl. 6, fig. 1). This creature has been identified with the urus-ox, a beast which is extinct in most parts of the world. Before it there is always placed a curious upright object, which on the better carved seals is seen to have been made of wickerwork (pl. 6, fig. 2). What this object really was is as yet uncertain. It has been identified as a fodder-rack, a cage for a bird, and an altar. That it was a cult-object is, however, certain, for at Mohenjo-daro and Harappa amulets have been found on which this object is carried on a staff in what was obviously a religious procession. This oxlike animal with its cult object is much the most common device on the seals of the Harappa culture, but there are other animals also on the seals. The collection in the Museum includes an elephant, an antelope (?) (pl. 6, fig. 3), and a shorthorned bull, which animal was always represented with its head lowered over a manger. The pictographic script above the animals has still to be deciphered, and of this there seems little prospect until a bilingual inscription has been found. We have great hopes that such an inscription may be found at Chanhu-daro, or, it may be, in Mesopotamia, for we have undoubted proof that the people of Harappa culture traded with Mesopotamia: objects obviously made in that country have been unearthed at Harappa and Mohenjo-daro and a considerable number of seals like those in our collection, and obviously of Indian workmanship, have been found in the Sumerian cities.

These seal-amulets were mostly carried on the person as amulets, but that they were also used as seals is shown by a seal-impression, which has on the back the marks of attachment to something, probably a bale of goods. Another seal-impression, which had been carried about a long time and so had been badly rubbed, shows two women supporting a staff between them from whose top project the branches of a *pipal* tree. This tree is still sacred in many parts of India.

The pottery of the Harappa culture is easily distinguishable from the wares of the Jhukar culture found above it. The designs painted in dense black on a highly burnished red slip distinguished it from any other pottery found in ancient India (pl. 6, fig. 4). A very common motif is based on a series of intersecting circles, on some of the sherds hardly recognizable, but on others so finely painted as to be almost mathematical (pl. 7, fig. 1). This motif was used on both large and small jars and is peculiar to the Harappa culture.

Another motif often used at Chanhu-daro, but rarely at Mohenjo-daro, is a scene of peacocks *en file*, drawn in a very sketchy way but nevertheless quite recognizable. This design was very generally used on the large jars, probably used for storing water, fragments of which were found all over Mound II. These jars were carried in rope slings suspended from the shoulders of the water carrier, and on this account the designs had often been partially worn away by the friction of the sling. Even quite small vessels were ornamented with paint, even if only with a few bands of red round the shoulder.

Certain small pottery vessels, all very much the same size and shape, seem to have been supplied by shopkeepers to purchasers of small quantities of cooking oil and the like, as at the present day. Other small jars with extraordinarily narrow mouths once contained an eye paint, which cosmetic was apparently used by men and women alike. Of particular importance is the bronze cosmetic jar with fluted sides, which is a notable feature of the Museum collection (pl. 3, fig. 3). Here might be mentioned a rectangular slip of red ochre with a beveled end, whose shape makes it more than likely that is was used as a face paint, if not actually as lipstick.

The small cones of pottery or shell which were found in the Harappa levels at Chanhu-daro are somewhat of an enigma. Very similar cones served an architectural purpose at Warka, Ur, and other early

Sumerian sites, but insufficient numbers have been found at the Indian sites to warrant the assumption that they were put to a like use. They may have been cult objects, or even skittles to be knocked over with marbles; I am inclined to regard them as the former, for they appear among the motifs on some of the painted pottery.

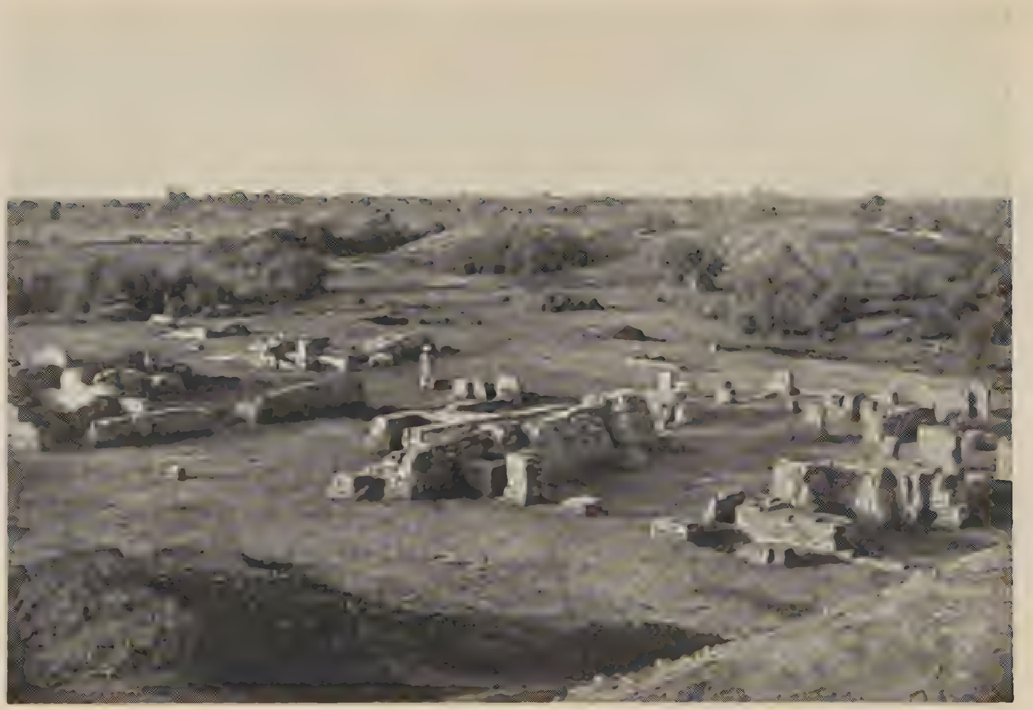
A large number of chert weights, carefully made and polished, form part of the Museum collection. They are nearly always cubical, and they belong to a definite system, with the simple ratios 1, 2, 4, 8, etc. In weight they vary remarkably little from those found at Mohenjo-daro, and similar weights from Harappa, more than 400 miles NE. of Chanhu-daro, have the same actual weights according to their respective sizes, proof that the authorities of those days exercised strict supervision over this very necessary adjunct of trade. Indeed, it is probable that some of the more carefully finished weights exhibited in the Museum were master weights by which others could be tested and rectified.

In the uppermost level of the Harappa culture there were but few intact buildings, though relics of houses and an extensive drainage system were found in this stratum all over Mound II. The occupation level below was in a better state of preservation, and streets and lanes, each with its houses and drains, were more or less intact and could be satisfactorily planned. Remains of a still earlier occupation were revealed in the upper part of a large cutting that was made in the western side of the mound to test the strata below (pl. 7, fig. 2), and at still lower levels were found traces of other occupations until the subsoil water prohibited any further digging. One very striking feature of these occupation levels in Mound II was that each was separated from those below and above by a considerable lapse of time. At Mohenjo-daro one occupation followed on another in swift succession, the later builders simply using the walls of their predecessors as foundations, thus preserving the alinement of the streets and houses over a very long period. At Chanhu-daro quite a considerable amount of debris separated the two uppermost Harappa occupations, and the buildings in the stratum next below these two were orientated quite differently from those above them. Indeed, we found ample evidence that it was destructive floods that caused the city to be deserted for considerable periods of time, during which large quantities of bricks were removed to build elsewhere. The walls of the three upper occupations of the Harappa culture had in some cases been so undermined by flood water, and tilted by the consequent subsidence, that we had to remove the upper parts to avoid risk of their falling on our workers. Even the brick flooring of rooms had subsided here and there. We at first thought that this irregularity of the walls was due to earthquake; but, had that been so, the rooms would have contained fallen bricks. At least three floods, the third of which was perhaps the great flood that led to the desertion of

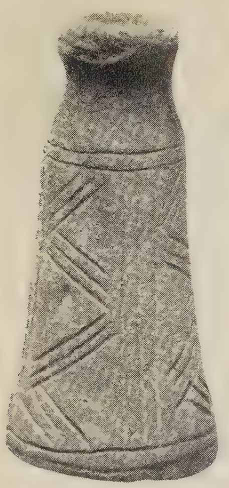
Mohenjo-daro, have left their traces at Chanhu-daro. Living on the banks of a great river running through an alluvial plain must have proved even more disconcerting in ancient times than it does today in many parts of the world.

The bricks used at Chanhu-daro were very much the same size as those of the other Indus cities; they average 11 by 5½ by 2½ inches. Made of well-fired clay, they are well-shaped but have no frogging of any kind. The mud mortar used amply served its purpose. They were laid to dry as they were shaped in open molds, and occasionally one is found with the impress of an animal's foot. For special purposes, such as lining wells, wedge-shaped bricks were made, and angle-bricks and half-sized bricks have been found. Bricks were also cut into various forms after being laid, as in the recesses of water-chutes; and those forming the corners at the junctions of drainage channels were often carefully rounded off with a chisel so as to impede the flow of water as little as possible (pl. 8). Most of the drains were made of ordinary bricks, and they were laid only a few inches below the surface of the ground so that they might be got at easily for cleaning. Owing to the demolition of many of the houses for the sake of their bricks, whenever the site was deserted, few of the bathrooms were found intact. Those few were simple platforms, of carefully laid bricks edged all round to a height of some 2 inches with bricks laid on edge; the water flowed away through an opening that sometimes communicated with a latrine situated between the bath and the street wall, and thence through an aperture in which the effluents passed to the street drain outside (pl. 9). There is no doubt that the sanitary system of the ancient Indus cities surpassed any other of contemporary date, and it is quite safe to say that it was superior to that in many modern oriental cities, which civilization seems barely to touch.

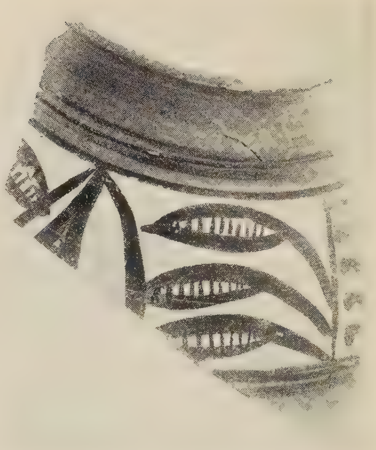
After the partial leveling of Mound II, a trial excavation was commenced on the summit of Mound I (pl. 10). Here several buildings were laid bare, also of the Harappa culture, but slightly later in date than those in Mound II. It seems that Mound I was occupied by the people of that culture later than was Mound II. Here, too, a few sherds of the Jhukar culture were found in the uppermost part of the mound, but so few that it seems that the Jhukar people only visited and never actually lived on the mound. Mound I offers scope for considerable and profitable investigation, and there is reason to think that it will prove even more productive of museum objects than the fortunate finds in Mound II which have so greatly widened the horizon of our knowledge. The discoveries of a new phase of Indian history with far-flung cultural connections, and metal objects of types never found before, together with fresh insight into the various arts and crafts of a great civilization that 20 years ago was unknown and unsuspected; such are the results of one small season's work of America's first archeological expedition to India.



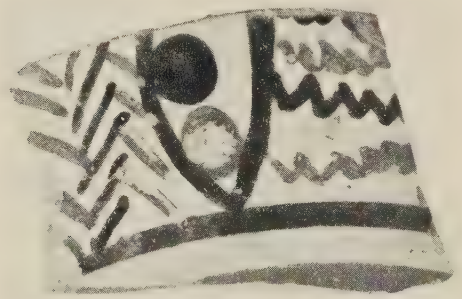
CHANHU-DARO. MOUND I IN THE DISTANCE; MOUND II IN THE FOREGROUND



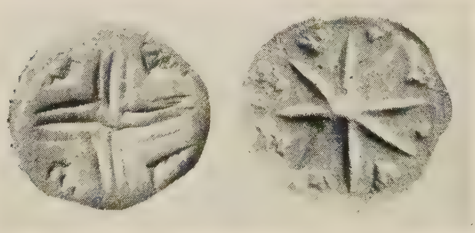
1. LATE GRAY WARE.



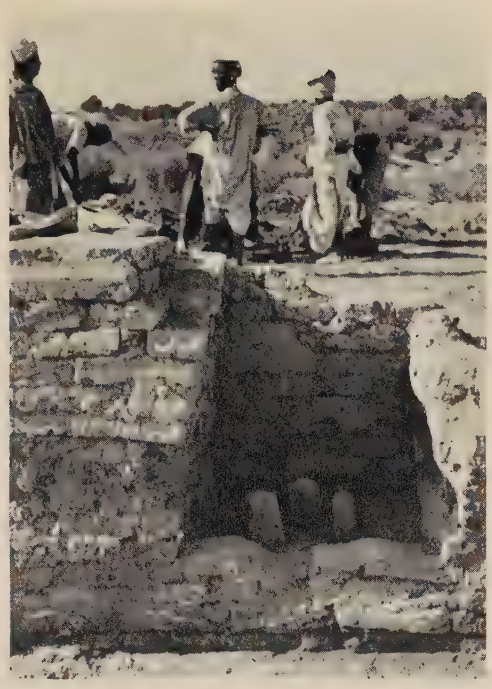
2. POLYCHROME WARE, JHUKAR CULTURE.



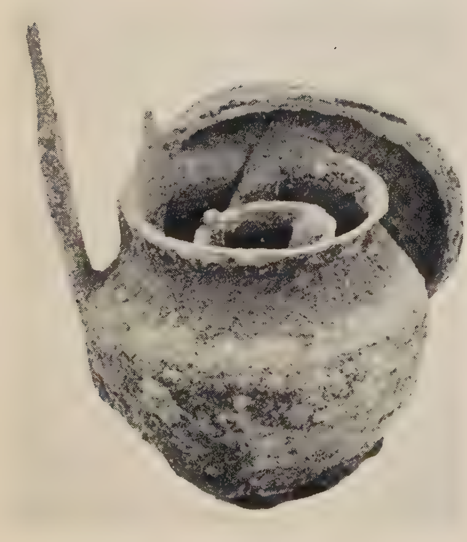
3. POLYCHROME WARE, JHUKAR CULTURE



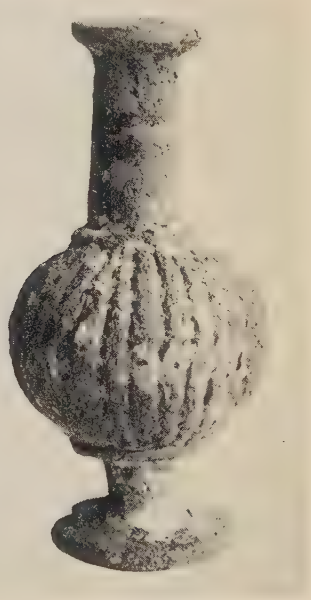
4. CAST OF A SEAL-AMULET, JHUKAR CULTURE.



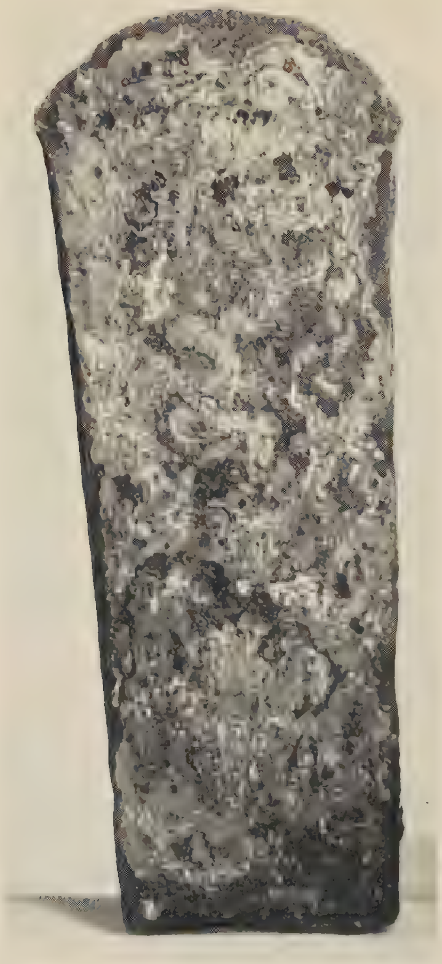
1. FIREPLACE IN A HOUSE OF THE JHUKAR CULTURE.



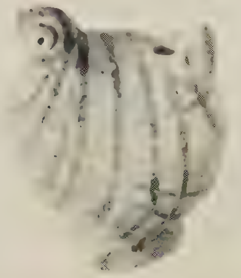
2. BRONZE UTENSILS AS FOUND, HARAPPA CULTURE.



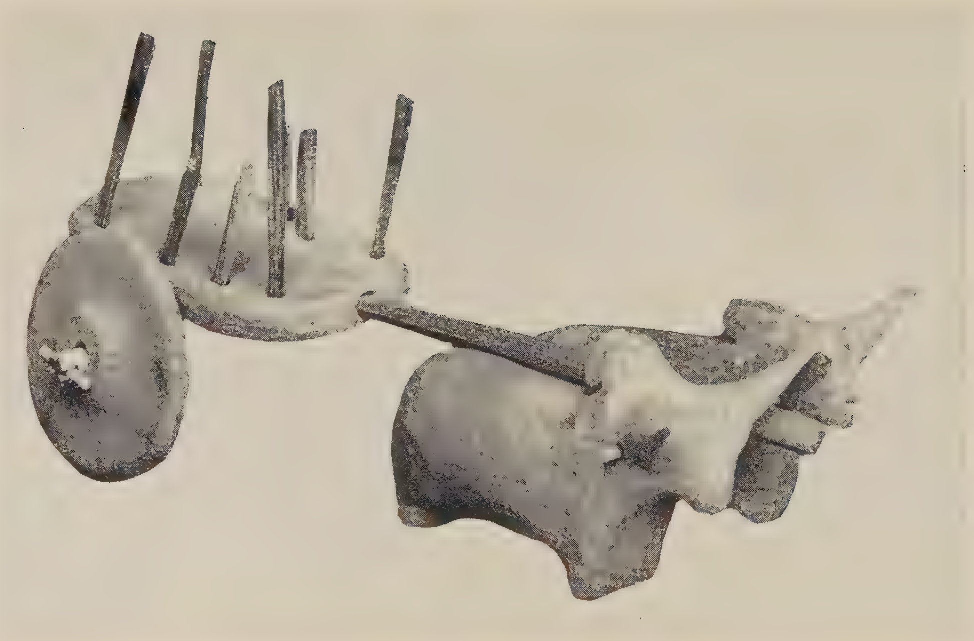
3. BRONZE COSMETIC JAR, HARAPPA CULTURE.



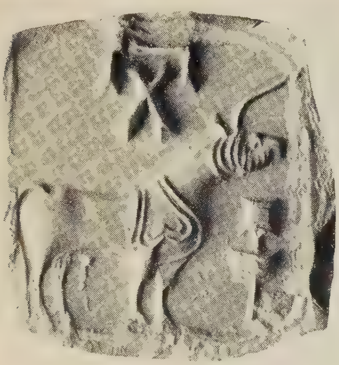
1. BLADE-AXE, HARAPPA CULTURE.



2. WHISTLE IN THE SHAPE OF A HEN, HARAPPA CULTURE.



TOY CART DRAWN BY HUMPED OXEN, HARAPPA CULTURE.



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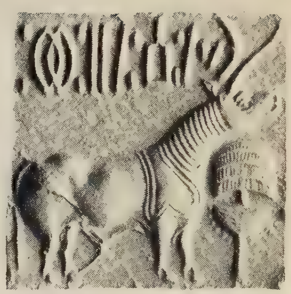

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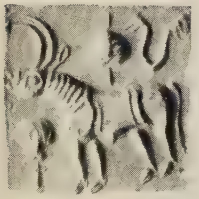

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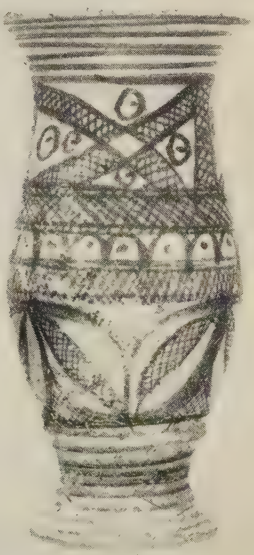

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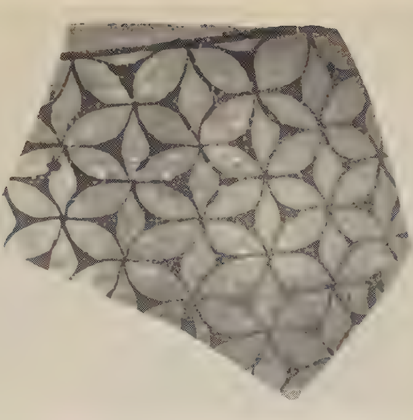
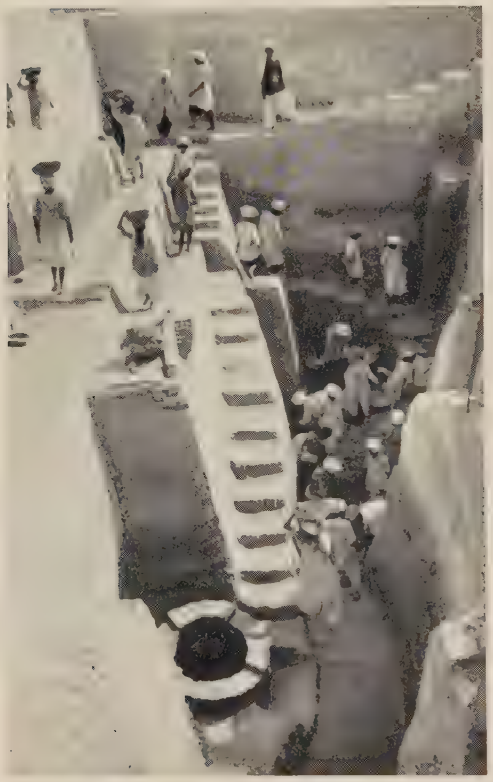
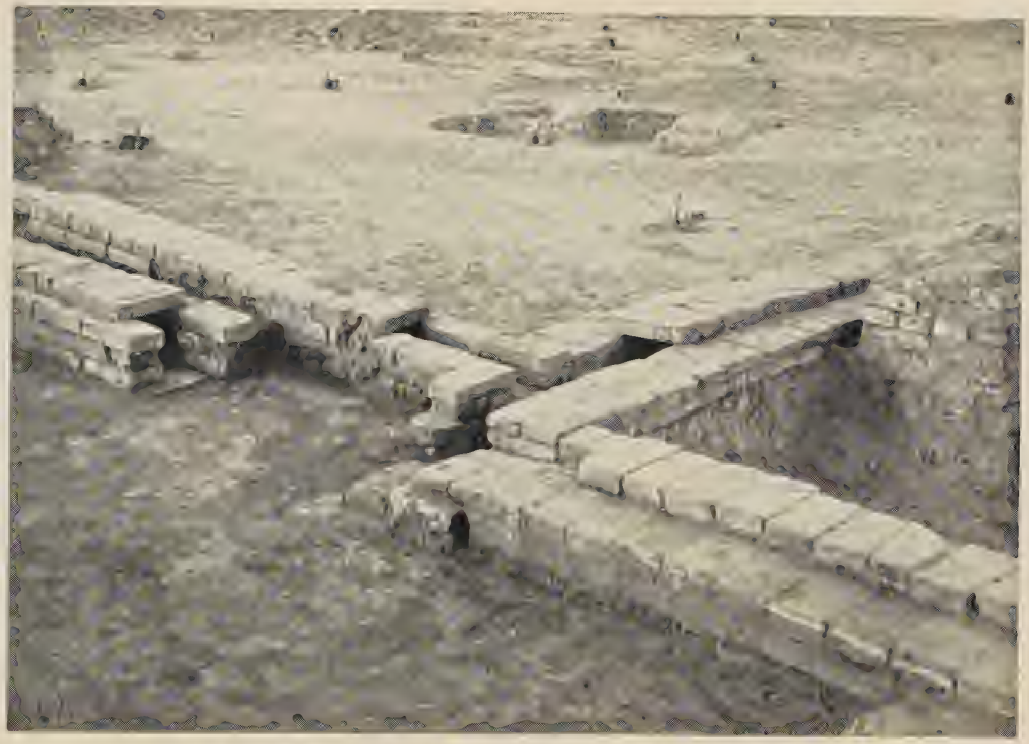
1, 2, 3. THREE SEAL-AMULETS, HARAPPA CULTURE. 4. BLACK ON RED WARE, HARAPPA CULTURE.



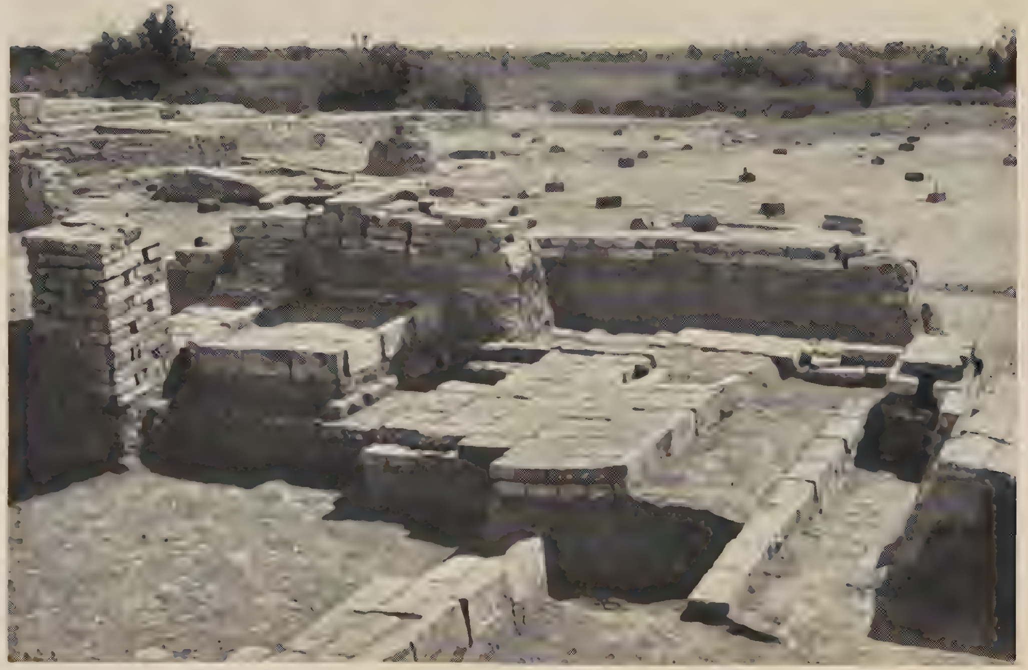
1. BLACK ON RED WARE, HARAPPA CULTURE.



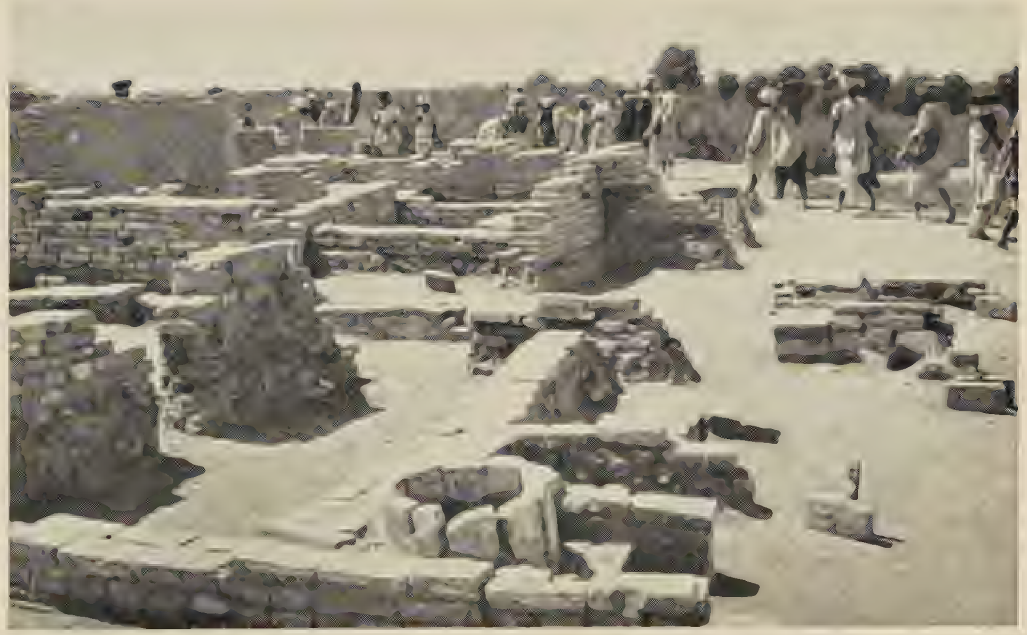
2. TRIAL CUTTING BELOW LEVEL EXCAVATED THIS YEAR, SHOWING WELL BUILT BY EARLIER DWELLERS ON THE SITE.



Brick Drain Laid Under Street, Harappa Culture



PAVEMENT OF A BATHROOM, WITH BATH-PLATFORM EDGED WITH BRICKS, HARAPPA CULTURE.



TRIAL EXCAVATION OF MOUND I, SHOWING WALLS OF HOUSES.

RAS SHAMRA: CANAANITE CIVILIZATION AND LANGUAGE

By Zellig S. Harris

[With 4 plates]

During the last hundred years the work of archeologists and philologists has brought within reach of our knowledge the civilizations which preceded ours. There are still many who mock at archeology as the innocuous digging up of pieces of ancient pots, and many more to whom archeology is merely a romantic search for objects of gold or for material of anecdotal interest about ancient kings and queens. But to those who understand the meaning of history, archeology has the invaluable function of making available for historical study the facts of past civilizations. From finds in many sites, and from the decipherment of countless inscriptions, we have been able to piece together some knowledge of the cultures and social structures and languages of Egypt and of the Mesopotamian areas. More recently, excavations in Asia Minor have been giving us a picture of early civilizations in that area.

In Syria-Palestine, however, there has been comparatively little large-scale excavation. The civilization of that area was not unknown to us, both from the Hebrew reactions to it in the Old Testament, and from its later contacts with the Greeks and Romans. From our knowledge of Egyptian and Mesopotamian history, we gathered that this was a politically weak area of small city-states. There was no far-reaching empire here with great kings and much gold, and the first excavations in Palestine yielded few objects of headline value. Partly for these reasons, partly because of the negative judgment of the Bible, the early civilization of this area was held of little importance. The Phoenicians were explained as merely borrowers of cultural traits, or at best mediators between great cultures—as though cultures did not normally borrow and mediate and adapt. But in spite of such value judgments which ill befit historians, people have long been eager for a direct word from this civilization which borders in so many points upon those which preceded and fathered ours.

Ras Shamra is the first site to give us the beginnings of an authentic general picture of that culture, the first to yield ancient Canaanite literature. The spectacular character of some of its finds have attracted wide notice, but its importance for our understanding of the history and linguistics of that area is greater even than the interest it has evoked in the scholarly world.

DISCOVERY

The excavations at Ras Shamra began simply. Early in 1928 an Alouite peasant, working on his land on the shore of the Mediterranean struck a stone slab which, upon removal, disclosed a stairway leading to an underground passage. It was an old vaulted tomb, and the peasant recovered from it some objects of gold. News of this reached M. Virolleaud, director of antiquities in the French Mandatory Government over Syria, and in the following winter a French archeological expedition was sent there under MM. C. F. A. Schaeffer and G. Chenet. They excavated at the first spot, a bay called Minet el–Beida, and found additional tombs; toward the end of the season they worked on the mound nearby, and unearthed not only many weapons, statuettes, and other objects, but also a store of clay tablets, some written in Akkadian cuneiform, others in a new and unknown cuneiform alphabet. This last discovery justly received unequaled attention, and the continuation of the excavation was assured. The work has been carried through with unimpeachable method, a fact deserving of note in view of the many dangers of commission and omission in archeological work and the importance of methodical and technical operation. M. Schaeffer has published the annual reports in the French journal Syria, where M. Virolleaud gives unusually clear and exact copies of the wealth of important inscriptions which have come to light.

THE PLACE

Minet el–Beida (White Port) is a small bay in the northermost part of the eastern (Syrian) coast of the Mediterranean Sea, about 15 kilometers north of Latakia. It is the spot on the Syrian coast opposite the eastern tip of Cyprus, which can be seen from the highlands behind the bay. About 1 mile inland stands the large tell (mound covering ancient ruins) of Ras esh–Shamra (Fennel Head), 20 meters high and almost 1 kilometer in diagonal. There are other tells along the coast, hiding ruins of other cities, while just to the north rises the promontory of Mons Casius, 1,760 meters high. What with its prominent position opposite Cyprus, and its overland passes across the mountains to the Syrian hinterland, this spot was a natural location for the development of one of the great cities of the ancient Near East.

THE SUCCESSIVE OCCUPATIONS

So far, only a small part of the surface of the tell has been excavated, but in that section the digging has gone all the way down to virgin soil. We may, therefore, try to collect the general facts about each stratum, going down from the topmost (historically most recent) level:

Stratum I–A—Middle of fourteenth-thirteenth century B. C.—The finds, both at Ras Shamra and at Minet el–Beida, are overwhelmingly Mycenaean. There are vaulted tombs much like those at Mycenae, usually with stone stairways and small windows. There are classical Mycenaean painted urns of many kinds, small perfume vases, many of them intact, large terra-cotta jars for wine and oil, tall Mycenaean goblets in the form of feminine heads. Some are quite like similar objects found at Enkomi (ancient Salamis) on the tip of Cyprus opposite Ras Shamra, having even the same potter's marks. Much of this must, therefore, have been imported, but there are signs of such pottery having been made locally, too. There are also delicate objects of porcelain and glass, ivory boxes for boudoir paints, Egyptian alabaster vases. Tools and weapons—daggers, ax heads, long swords—are of bronze; jewelry is of bronze and various semiprecious stones, with necklaces of Egyptian pearls, gold pendants of Astarte in Phoenician style, and some rare iron jewelry foreshadowing the approach of the iron age. Figurines of goddesses and gods, and bones of sacrificed sheep give a hint of the religion, and some small tablets in the cuneiform alphabet have been found at the tell, with one or two at Minet el–Beida.

Stratum I–B—Fifteenth–middle of fourteenth century B. C.—The port settlement at Minet el–Beida seems to have been founded during this period. Both at the port and at the tell there are Cyprian objects, but not Mycenaean, and Rhodian pottery such as is also found in Cyprus, the Orontes valley in Syria, and Egypt. From the end of this period come a gold plate and gold bowl of fine workmanship, representing a hunt and various symbolic figures. The pottery is largely local, of Canaanite types. Here, too, are the foundations of two reconstructed temples, one of Dagan, with two alphabetic inscriptions dedicated to him, and the other of Baal, with an Egyptian stele calling him Baal of Sapun. It is near this temple that the great store of tablets was found, containing long mythological poems, syllabaries for teaching cuneiform writing, and texts of cult instructions; this must have been the priestly scribal school. Other small tablets have been found elsewhere, and also a group of ax heads inscribed in the cuneiform alphabet "ax of the chief priest."

Stratum II—Twenty-first–sixteenth century B. C.—Here are the first foundations of the temples of Dagan and Baal, and from the end of this period comes an Akkadian letter written by the local king Niqmed.

The pottery is almost entirely Canaanite; i. e., of the types found at contemporary Palestinian sites. Only toward the end do we find a few Cyprian vases. There are figurines of deities, bronze weapons, silver and bronze jewelry much like those found at the great Phoenician city Byblos. Egyptian objects, of the twelfth dynasty of Egypt, are numerous, including many scarabs, a sphinx which was the gift of Pharaoh Amenemhat III, and the statute of an Egyptian commissioner to Ras Shamra. Below this stratum is a large layer of sterile soil, showing that some time elapsed after the destruction of the city of stratum III before the site was reoccupied.

Stratum III—Late fourth millennium–most of third millennium B. C.—The upper part of this stratum yields poor unpainted pottery of Canaanite type. Below it is a fine painted pottery in geometric patterns, similar to the Mesopotamian pottery of Jemdet Nasr. Pottery of this type, found in Cyprus, can now be approximately dated by comparison with Ras Shamra. There are large buildings of unbaked brick.

Stratum IV—Fourth millennium.—The top of this stratum again shows unpainted pottery. Then comes polychrome painted pottery of geometric design and rare beauty, different from that of stratum III and similar to the famous pottery of early Susa I in Persia, el-Obeid, and the early levels of Carchemish and Niniveh. There is no metal here; tools are of stone and flint, of obsidian and silex. There are traces of brick buildings which have been burned in some great fire.

Stratum V.—This stratum of unknown duration is definitely prebronze. Tools are of stone only, with great use of silex; obsidian is rare. The pottery is archaic and unpainted. The lower levels show neolithic culture, and below that is virgin soil.

HISTORY OF UGARIT

The site of Ras Shamra has been identified, first by historical inference, and later by testimony of its own tablets, as the ancient Ugarit, known from the Amarna correspondence. It exhibits an antiquity which rivals the great mounds of Mesopotamia, having been occupied from neolithic times. In successive ages it was inhabited by peoples of the successive painted pottery cultures, related culturally to the broad areas of painted pottery in Asia Minor, Mesopotamia, Persia. During the third millennium, at a time when Egypt and Babylonia already had centralized governments, there appears a culture primarily related with the Canaanite area to the south. We may call this the coming of the Phoenicians (or Canaanites) into Ugarit, although we must be wary of identifying cultural changes with ethnic movements (culture being understood to include also all forms of material civilization); not every great change in cultural type means the coming of a new people, for cultural forms often spread far beyond the borders of the peoples who developed them.

Early in the second millennium Ugarit developed into an important trade city, now certainly Phoenician. It was important to Egypt during the twelfth dynasty, and was perhaps under its domination. The end of this period is the time of King Niqmed, in whose day the long mythological poems may have been written. Some time during this period, perhaps in the uncertain times between the Middle and New Kingdoms in Egypt, the fortifications of Ugarit were dismantled.

With the New Kingdom of Egypt, Ugarit continued in its importance, probably, like the other cities, an Egyptian protectorate. During the troubled times of the Amarna correspondence, Ugarit was sacked, apparently by a Hittite army around 1365 B. C.

After this destruction, with the weakening of Egyptian control and commercial contacts, Mycenaeans seem to have come to Ugarit in large numbers. Around the port of Ugarit an international settlement of sailors and traders had grown up during the preceding period; it was now large, and perhaps chiefly Cyprian in population, though we need not infer that Ugarit was conquered by Mycenaeans. The city was independent of Egypt; in the great battle of Qadesh, Ugaritic troops were among the enemies of Ramses II.

When the Peoples of the Sea spread over the eastern Mediterranean, they seem to have either destroyed the city, or settled in it until it was destroyed, perhaps (though improbably) by Tiglath–Pileser I of Assyria on his Syrian campaign.

At all events, Ugarit was destroyed at about the end of the twelfth century. The site was inhabited from the eighth century, for a time perhaps by a non-Semitic (Greek?) population using sarcophagus burial, bronze jewelry and instruments, iron weapons—Ugarit is now in the iron age. Later periods yield Neo-Babylonian and Egyptian objects of the sixth and fifth centuries. The city maintained itself into Hellenistic times, for we find Greek coins of the fourth century B. C., but under the Hellenistic Seleucid kings of Syria its place was gradually taken by Latakia, a seaport a few miles to the south. Since then the site itself has remained uninhabited.

UGARIT IN THE ANCIENT WORLD

In ancient times Ugarit was one of a chain of seaports along the eastern coast of the Mediterranean, marked to this day by tells of covered ruins. These and the inland towns of Syria–Palestine were all separate units. There did not exist here the same local needs for united action which had caused the growth of centralized governments in Egypt and Mesopotamia. But language, culture, and population were much the same over Syria–Palestine; and the coastal towns in particular, what with the similarity of their occupations and interests, had developed occasional cooperation—at times perhaps approaching a trade guild of the great commercial towns. Though it was far to the north, Ugarit must have had considerable contact with the Phoenician cities.

Its cultural and commercial contact with Mesopotamia must go back to earliest times, witness the objects of Mesopotamian origin and the use of cuneiform writing. The continued contact may be gathered from a letter (c. 1300 B. C.) of an Assyrian, Belubur, to Ilshar in Ugarit, informing him of a document he was sending to be read to the Queen of Ugarit.

With Egypt, Ugarit had commercial and political relations, at least from the beginning of the second millennium, though these can hardly be compared with the close relations between Byblos and Egypt.

The Mycenaean contacts, which became so prominent later, began with small trade between Ugarit and Salamis in Cyprus, in about the seventeenth century. At that time the pottery in Salamis, as shown by the Enkomi excavation, was almost entirely Syrian. During the fifteenth–fourteenth centuries Salamis had both Cyprian and Syrian pottery; this is the period when Ugarit had a great deal of Cyprian pottery, and perhaps the beginning of a Cyprian population at its port. In the end of the fourteenth century and during the thirteenth, Salamis had only Cyprian and generally Mycenaean pottery; at this time Mycenaean objects and tombs were paramount in Ugarit, and Mycenaean ware is found elsewhere in Syria. The Peoples of the Sea who took Ugarit also cut off Mycenaean trade in general; it was only after that break that the Phoenicians resumed this trade with the Greeks who inherited the Mycenaean area. Memories of this early contact between the Aegean world and Syria came down to the Greeks in the form of legends such as that of Cadmos of Thebes who lived long in Phoenicia, and upon his return brought the alphabet, the "Cadmaean letters." More significant for the early period, and especially for Ugarit, is the legend told by the Byzantine Malalas about the marriage of Kasos (eponym of Mount Casius) with Kitia (eponym of the Cyprian city Citium) daughter of Salaminos (the city Salamis) of Cyprus; after their marriage they colonized the region of Mount Casius (just north of Ugarit) with Cyprians and Cretans. The inference of such legends is that it was Aegean traders who brought Phoenician culture home after visiting Syria, rather than Phoenician traders who visited the Aegean and taught it their culture; however, legends are often guilty of projection into the past, and we cannot be sure as yet of the actual course of contact between the two cultures.

THE POPULATION OF UGARIT

Several races and cultures were represented at Ugarit. The chief element, at least from the third millennium, was the Semitic Canaanite, as may be seen from the pottery, the language of most of the tablets, the majority of personal names and neighboring place names recorded in the tablets.

Of the other peoples, the Cyprians must have been prominent in the port settlement, as appears from the archeological evidence. An enigmatic text from Ugarit mentions Alasiyans (Cyprians), Hittites, Hurrians, and other peoples. And among the personal names, and the names of places from which various persons are said to have come, we have many which are not Semitic.

Next to the Canaanite, the most important group seems to have been the Hurrian. The Hurrians were, during the second millennium, a widespread people. Hurrian texts and names are found during the middle of that millennium in the neighborhood of Assyria, in Asia Minor, in Syria, and Palestine. We know neither the extent of their spread nor what peoples and languages were comprised in them, but we know their influence was great. The "Hittite" culture of North Syria (called Hatti land by the Assyrians) was in all probability Hurrian, being quite different from that of the Hittite center in Asia Minor. The Hurrians were an important element in the population of Palestine-Syria. The Horites of the Bible were shown by Professor Speiser to have been Hurrians,[1] and quite a number of the early Palestinian tribal and personal names mentioned in the Bible are Hurrian; e. g., Kenaz, the Perizzi, the names in Genesis 36: 20 ff., such as Dishan (Hurrian Taishenni). In Ras Shamra there are many Hurrian names; in one letter all the people involved are Hurrians, although they use the Semitic language, just as the Hurrians of Nuzi used the Semitic Assyrian.

Ras Shamra has also yielded a syllabary (sign dictionary) in Sumerian and Hurrian (to teach cuneiform writing to Hurrian scribes?), and several texts in the Ugaritic alphabet. Although our knowledge of Hurrian is limited, we know it is this language because of formal similarities with the language of the famous Mitanni letter (of Tushratta, king of the Hurrian land Mitanni, to the Pharaoh of Egypt) and with the related language of certain of the tablets found at the Hittite capital Boghazkoi in Asia Minor. The Sumerian-Hurrian syllabary, interpreted by Professor Thureau-Dangin, has been of great value in telling us more of the structure of the language, and in identifying the meaning of some of the suffixes and words. Although this language is related to the other Hurrian dialects of which we know, it may constitute a different dialect. When the alphabetic texts are interpreted, Ras Shamra will have become one of the chief sources for our knowledge of this great but little-known people.

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[1] Speiser, E. A., Mesopotamian origins, pp. 131 ff.; Ethnic movements in the Near East in the second millenium B. C., Annual Amer. Schools Oriental Res., 1933.

COMMERCE AND INDUSTRY

The importance of Ugarit derived from its geographical position. It was apparently at the head of one of the chief trade routes inland from the Mediterranean: The route to Aleppo and on to the Euphrates Valley and Mesopotamia. Goods from the north Phoenician cities probably went east by way of Ugarit. In addition Ugarit had a lively trade with Egypt which it supplied with the highly valued boxwood. Its chief trade was undoubtedly in bronze. Salamis in Cyprus and Ugarit on the Syrian coast were the stations in the passage of bronze from Cyprus, great source of copper in the ancient Near East, to Syria and Mesopotamia. With the bronze, other objects passed in trade, and when Mycenaean pottery is found in Qatna in Syria, or when a vase of Salamis type is found in Ashur, we may presume that they passed through the stalls and storerooms of Ugarit. Later, after the period of the Peoples of the Sea, when iron began to replace bronze as the most necessary of metals, the extent of the bronze trade fell decisively, and Ugarit never regained the importance it had had before the twelfth century.

Like the other cities, Ugarit had its local industries, partly to satisfy its needs at home, and partly in conjunction with its commerce. There are traces of a pottery industry, and of a purple industry for the dyeing of cloths used at home and in trade. There was also a bronze industry, and the unused deposits of copper ore and slag which have been recovered by the excavators were shown by analysis to have come from Enkomi.

LIFE IN UGARIT

In spite of the many objects found in the excavations, we still know little of how people lived in the various periods. The large majority of texts are of mythological or cult content; there are a few letters of more or less personal nature (e. g., the Akkadian letter about the escape of King Niqmed's equerry), and perhaps one of political content; there are also some lists of names.

Even so, we can record that during the late Bronze Age (stratum I), at the apex of the copper trade, Ugarit was a rich city. The houses are large and spaced well apart; the more important ones had vaulted tombs attached. The weapons, jewelry, and various objects in gold and silver, bronze, and pottery, are numerous and well-made.

Little is known of the methods of trading, but we do know that they used a talent of 3,000 shekels, as against the usual one of 3,600; the same short talent is employed in Exodus 38: 25–7. A text of veterinary cures gives an insight into their treatment of the then rare and valuable horses; interesting is its frequent recommendation of dried fig cakes, prescribed as a medicine in Isaiah 38: 21, and raisins, frequently mentioned in the Bible as a food used with the dried figs.

From their myths we may learn something of their own life. Thus a marriage of the gods, which must reflect current or past customs in their own marriages, entails the father's wedding gift to his daughter (Biblical shilluhim), and the estate brought by the bride from her father's house, and the old bride-price (Biblical mohar) paid by the suitor; the terms used are the same as in the Bible and in the (Hurrian) Assyrian Nuzi texts.

The art of Ugarit was of varying quality. The gold bowl and plate are outstanding and rich, but do not equal the best contemporary work of Egypt and Cyprus. They show Mycenaean and Egyptian influence, and exhibit motifs which can best be explained from Cyprus, Mesopotamia, and perhaps other Asiatic sources; similar influences may be seen in the locally manufactured cylinder seals. One statuette of Baal is noteworthy for being made of bronze with gold, silver, electrum, and green steatite used for various parts of the statue.

GODS, MYTHS, WORSHIP

The large texts which we have are apparently all religious myths; what other literature there may have been, we do not know. There was probably little if any secular written literature, for reading was an accomplishment of professional scribes only, and even these myths seem to have been written down primarily as an aid to priestly recitation. They are of the greatest interest to students of the ancient east and to students of religion and culture, being the first direct material of Phoenician–Canaanite religion. The Biblical references to this religion were fragmentary and negative; the Greek descriptions, as in Lucian's de Dea Syria, are late and alien. The fullest account was that given at fourth hand by Eusebius (Praeparatio evangelica i 9) and attributed to a Phoenician priest Sanchuniathon; most scholars doubted its authenticity. Now both this and the brief descriptions in Ezekiel and elsewhere in the Bible are well borne out and incomparably amplified by the direct evidence.

Ugarit had its own pantheon, generally similar to that of the other Phoenician-Syrian cities. There was a chief god Il (Biblical El), father of the gods, and his consort Athirat of the Sea (Biblical Ashera, thus shown to be a true deity, cf. 1 Kings 18: 19, not merely a cult pole), whose relation to the sea may have some connection with the Cyprian Aphrodite's sea characteristics; one calls to mind the Greek representations of Aphrodite rising from the waves. There is the grain god Dagan, and his son Baal, or Aliyan Baal. Aliyan was the Adonis of Ugarit, the vegetation god who died with the scorching summer and rose to life with the returning rains; his consort is Anat, and his perpetual enemy is Mot, god of the death of vegetation, while Shapsh, goddess of the sun, often comes to support him. There are many other deities, some of whom have not appeared in the myths, but are mentioned in lists of sacrifices or of gods; such are Rashp, Athtart, a possible Milkam (Biblical Milkom?), all known from the Bible (where Astarte, i. e., Athtart, is the consort of Baal). There are genii who serve the gods, e. g., the divine constructor Kathar-Hasis (a double name "able-and-understanding"), mentioned in Sanchuniathon as Chusor. And there is a general divine population, the Banê Ilim (cf., the Biblical Bne Elohim). All live on the heights of Sapun ("North"), the Olympus of this pantheon, which is Mount Casius, north of Ras Shamra; cf. here Tyre's "Holy Mount" in Ezekiel 28: 14, and "Mount Zion in the Recesses of the North (Saphon)" in Psalms 48: 3. It is revealing to find here a reference to the mythical Leviathan (Lotan) in almost the exact words used of him in the Bible, and a long legend about Danil, who must be the Canaanite myth hero referred to in Ezekiel 14: 14 and used as model for the Biblical story of Daniel.

The mythological poems tell of the struggle between Aliyan and Mot, and the death and resurrection of Aliyan Baal—this is the widespread Adonis myth. There is a myth of the building of Aliyan's divine temple (perhaps recited at the completion of his temple in Ugarit), and one of the victory of Aliyan, as Lord of the Land, over the gods of the Sea. There is a myth of the marriage of the moon gods, Yarih and Nikkal, and one of the birth of the "Gracious Gods."

Parts of these myths can be read with ease, but because of our lack of knowledge of their background, and our frequent inability to fathom their exact meaning, much is uncertain even now. There have been attempts to read these poems as historical traditions, and to prove from them that the Phoenicians came north to the Phoenician-Syrian coast from the south of Palestine where they had originally dwelt. The evidence proposed was the identification of south Palestine names in the poems, but most of these identifications cannot be defended; many are accidental similarities and must, for the sense of the poems, be interpreted otherwise. The renderings of the poems by such men as Professors Albright, Montgomery, and Ginsberg leave no room for their interpretation as historical traditions. Even more erroneous is the attempt to identify the origin of the Hebrew people with this assumed south Palestine Phoenician center. There is no archeological evidence for placing the Phoenicians there, and as to the forebears of the Hebrew people, we have good evidence that they were not of the Canaanite group but entered Palestine for the most part during the middle of the second millennium. This divergence of interpretations reveals once more how little one can trust one's reading of a text, how easy it is to read into it unintentionally but effectively any ideas to which one is accustomed or which one unconsciously wishes to find. For this reason it is always best to rely upon the incontrovertible linguistic evidence of the linguistic forms as they appear in the text, and to draw only such minimum content as appears most "simply" from the material itself.

The smaller tablets include chiefly lists of temples and gods (including non-Semitic), lists of temple goods, lists of sacrifices, directions for preparing sacrifices, and ritual prayers. The parallels with Hebrew religious practice are many. The animals which may be sacrificed are the same; many names of sacrifices are the same. But it is interesting that one sacrifice calls for the cooking of a kid in milk; this is prohibited in Exodus 13: 19, 34: 26. One asks if the Biblical prohibition arose in opposition to this rite, with the general Jewish separation of meat and milk foods developing therefrom, or whether that general custom preceded (from pre-Palestinian times) and explains the interdiction of the Canaanite rite.

Of the relation of this Canaanite religion to that of the Hebrew people, two things appear certain: Clearly the forefathers of the Hebrew people, when they settled in Palestine, took over much of Canaanite culture, including many of the cult practices, types of sacrifices, mythological heroes, even some of the moral proverbs, as witness the appearance in Ugarit of the phrase "pleading the plea of the widows, judging the cause of the orphans" (Danil 2v 8) which the Bible so frequently parallels. But it is even clearer that the bulk of the cultural and religious background of the Hebrew people was a different one. The Babylonian legends of the Bible (creation, deluge, Nimrod, Tower of Babel) are conspicuously absent from Ugarit. For various social and historical reasons, the Hebrews in Palestine, even with the assimilation of Canaanites into them, retained much of the culture which they had had in pre-Palestinian days, and although the final form of Hebrew culture was certainly no mere continuation of the old, it nevertheless remained fundamentally different from the Canaanite.

THE UGARITIC ALPHABET

DECIPHERMENT

Within a few months after the first great finds of tablets in 1929, Virolleaud published a set of excellent copies of the tablets in their unknown cuneiform signs. It was clear that the signs constituted an alphabet, for there were only about 30 of them used over and over again. The words were separated by short strokes, and it was found that most were of three or four letters. Virolleaud and the excavators thought that the script might be Cyprian, because of the extent of Cyprian material found at this stratum. Other scholars, judging by the probable Semitic population of Syria, and by the three- and four-letter groups, looked for a Semitic language with an alphabet in which only the consonants were written (as was the case in the Phoenician alphabet); in this case most words would have three letters, for the three consonants of the root, or four, for the root plus some affix. In May 1930 Professor Bauer communicated his first suggestions for decipherment; during the same time Professor Dhorme in Jerusalem was arriving at somewhat similar results. Both agreed on some of the letters, and each corrected from the other's suggestions.

There were no bilingual texts, and the process of deciphering involved considerable ingenuity. But as soon as the majority of signs had been correctly worked out, familiar words such as *alp*[2] ("ox") and *gdl* ("large") began to appear in the very first texts, and soon they were readable. Some characters remained in doubt even then. One which had been read *ƒ* turned out, when more texts were published, to be sometimes simply the two signs *p* and ayin (a Semitic laryngal), and sometimes a new sign with the value *ẓ*. Another sign, long taken as a variant for the *š*-sign, is seen to be a different sibilant character, apparently representing some Hurrian sound. One or two are still uncertain.

THE SCRIPT

The alphabet consists of simple cuneiform characters having no relation to the syllabic and ideographic (logographic) signs of Sumerian-Akkadian cuneiform writing, but similar in that they too are made of combinations of impressions of a wedge-shaped stylus on clay tablets. The writing runs from left to right, like Babylonian cuneiform, but unlike the Phoenician alphabet, which originated in a carved script and ran from right to left.

There are some 30 signs, all representing consonants; as in the Phoenician alphabet there are no signs for vowels. However, for the consonant aleph (the glottal stop) there are three signs, one each for aleph with *a*, *i*, and *u* vowels respectively. Each sign is of set form, but in the smaller tablets there appear certain signs the value of which has not yet been determined, which may be merely variant forms of some of the standard signs. There is one character (s^2) which occurs only in the smaller tablets, and which may be a second *s*-sign (entirely different in form) by the side of the usual *s* (which appears both in the poems and in these same small texts).

The spelling is fixed throughout; no word is written differently at one time than at another. This is hardly surprising, since each letter represented a different sound, so that properly there could be but one spelling for each word, but the absence of all slips indicates that the script was well-established at this time.

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[2] The three Ugaritic alephs will be here transcribed *a*, *i*, and *u*, so that *a* represents *a* spoken ['a] or [-a'], *i* represents ['i] or [-i'], and *u*, ['u] or [-u'].

In the long poems there are few errors in sign making (e. g. putting in of extra wedges). But in some of the small texts there are many such errors; in a few the letter *n* is regularly or usually made with four instead of three wedge-impressions, *r* with seven instead of five, and so on. It may be that some of these texts are exercises and students' work; the syllabaries found with them suggest that the site was a scribal school. Some have suggested that the less regularly written tablets are earlier and go back to a time when the alphabet was still not quite fixed; in that case the signs which occur only in the small tablets may be early variants, or characters which died out when the script was fixed. But there is little evidence to support this view.

A few tablets have been found with the letters reversed mirrorwise; the writing runs from right to left, and the individual signs, too, are turned around. Whether this had some magical significance is not clear as yet; the contents may be magical formulae.

For our understanding of these texts, and of their bearing upon the history of the alphabet, it is important to know their exact date. The great store of tablets was found in debris in stratum I–B (c. 1500–1365 B. C.), but some of them seem to have been built into the reconstruction of the contiguous temple, suggesting that they may in fact be older than this reconstruction. The colophon of some of the poems indicates that they were written down (copied from older texts?) during the reign of Niqmed, King of Ugarit; at the top of stratum II, i. e., just before 1500, an Akkadian letter was found written by a King Niqmed of Ugarit. If both refer to the same person, it follows that these tablets are of that time, c. 1500 B. C. Other tablets have been found elsewhere in the ruins and may well be later, in stratum I–B.

It is quite possible that this alphabet was created during stratum II, at Ugarit. How far the use of it or the knowledge of it spread, we cannot tell until other sites have been excavated. In Beth Shemesh, in south Palestine, there was found a tablet with a short inscription in the Ugaritic alphabet, written in reverse. The tablet has not as yet been successfully interpreted—it may be in a non-Semitic language—but it suffices to suggest that the alphabet of Ugarit was known over a wide area.

UGARITIC AND PHOENICIAN

The origin of the Ugaritic alphabet is unknown. It is all very well to say that the scribes of Ugarit, using the Akkadian cuneiform, created alphabetic signs for writing their own language, but how did they come upon the idea of alphabetic characters? We cannot explain it as a development from their knowledge of the syllabic cuneiform, for the alphabet is no natural development from syllabic writing. Once writing has reached the phonetic stage, each sign represents a natural syllabic division of a word. The signary may be reduced to the smallest syllabic divisions, but the signs will not be made to represent such divisions of words (i. e., such sounds or combinations of sounds) as are not normally pronounced "by themselves," that is, as separate syllables. There will, therefore, be no letters representing the nonsyllabic consonants. But it is precisely these that we have in both Phoenician and Ugaritic alphabets. In the former, we know the reason: the juncture of circumstances which led to the construction of the Phoenician alphabet on the acrophonic principle (the principle of having a sign represent the first sound of its name). In the case of Ugaritic, what was the reason?

The suggestion to derive the Ugaritic alphabet from the Akkadian cuneiform may be set aside. No impressive similarities have been established between Akkadian and Ugaritic signs, but even if there were similarities they would not explain the source of the idea of alphabetic writing. Similarly, there are no grounds for the suggestion that this alphabet was invented by non-Semites, a suggestion growing out of the existence of vocalic aleph signs. The alphabet seems definitely to fit the Semitic dialect of Ugarit, and the three aleph signs may have been a special adjustment for the Hurrian population, perhaps introduced for use in writing Hurrian.

We must investigate the possible relations with the Phoenician alphabet. The primitive inscriptions found at Serabit in Sinai show that the alphabet existed as early as the twentieth century B. C. (or, perhaps, the last pre-Hyksos period). The Phoenician alphabet proper has been carried back to about the thirteenth century, but recent Palestine excavations have yielded some 10 archaic inscriptions from between 1600 and 1200 B. C., all showing early stages of the Phoenician alphabet. Some have suggested that the Ugaritic alphabet is merely an attempt to transfer the Phoenician to use on clay tablets, but in that case we should expect far greater similarity between the letters of the two alphabets. The only close similarity is between the samek (*s*) of the Phoenician and the special Ugaritic s^2 mentioned above, which appears in a few of the small tablets and is entirely different from the ordinary *s*; this may, perhaps, be a variant made as a copy of the Phoenician letter, only to die out without gaining acceptance. It may be true that the forms of some Ugaritic letters are based on the Phoenician. Some scholars have suggested another point of connection between the two alphabets. In one of the texts, a Hurrian one at that, the letter *ayin* appears with a small circle about it. These scholars consider the circle to be the Phoenician *ayin*, used here as a diacritical mark to distinguish the Ugaritic *ayin* from the very similar *ṯ*. However, for various reasons this view should be rejected; the encircled sign in question probably represents a number or some other special mark, and this type of close relation between the two alphabets remains highly doubtful.

Nevertheless, the consonantal Ugaritic alphabet must have been modeled on the consonantal Phoenician alphabet. Only so can we explain why the Ugaritic alphabet has no signs for vowels even though it was created by people who knew Akkadian cuneiform, and vowels are the only simple sounds for which cuneiform did have separate signs. It may have been made with a sign-for-sign correspondence to the Phoenician, in which case it probably had to continue the list and add some signs for sounds which Phoenician did not have. But more probably it was modeled on the general acrophonic method of the Phoenician alphabet; just as the Phoenician had signs the value of which was the first sound of their names, so here cuneiform signs were made, with fixed names, and with acrophonic alphabetic values. We cannot be at all sure of this, for we do not have the names of the Ugaritic letters, but it is doubtful if the sounds were thought of analytically by themselves; more probably they were conceived as the different initial sounds of various words which "began differently."

Either way, the Ugaritic alphabet was probably not a slavish borrowing of the Phoenician, but a new creation based on a learning of the general idea or the underlying method of the Phoenician alphabet. We have here a fine example of the learning and independent application of cultural patterns, a type of transfer which often takes place in the spread of cultural forms. This imitating of the cultural pattern has occurred several times in the history of the alphabet—it figures in the very origin of the Phoenician alphabet—and is but another witness to the great adaptability of peoples in assimilating the cultural forms of their neighbors.

THE LANGUAGE OF UGARIT

WORKING OUT THE GRAMMAR

The language of Ugarit is of great interest for Semitic linguistics. It has brought important new facts to light, and has given body to some hypotheses. But it is not in itself a totally new Semitic language; it is a dialect closely related to other known Semitic dialects. When once the values of the alphabetic characters were deciphered, it was possible to understand large portions of the texts. Most of the words were recognizable; they were similar to Hebrew words, or to words known from Phoenician inscriptions, and were assumed to have the same meanings as their cognates (words in related languages which have developed from the same common word in the parent speech). Some words could not be made out at first, but were shown to have cognates in Akkadian or Arabic, or other more distant Semitic languages.

As the texts were read, the grammar began to reveal itself. Consonantal prefixes and affixes indicated something of the forms of verbs and nouns, since the functions of most of these affixes were known from other Semitic dialects. Of particular value were the three aleph signs, which revealed the vowel following the aleph (or the vowel preceding it, if there was none following); this served as the chief indication of the vocalization. Professor Friedrich soon showed that the word for "chair" was spelled *ksu* when it was in the nominative, *ksa* when in the accusative, *ksi* in the genitive. We must, therefore, assume that it represented [kussa'u, kussa'a, kussa'i][3] in the three positions, and that the old Semitic case-endings were still in use; hence, the word for sacrifice, always spelled *dbḥ*, must have been pronounced [dibḥu, dibḥa, dibḥi] in the three cases. Similarly, from verbs ending in aleph, Friedrich demonstrated the existence of various modes—an indicative ending in [u], e. g. in *tšu* "she raised" for [tišša'u], where the jussive is *tša* for [tišša'], and so on. The alephs also reveal the vocalization of the verb-system; thus the form written *amid*,

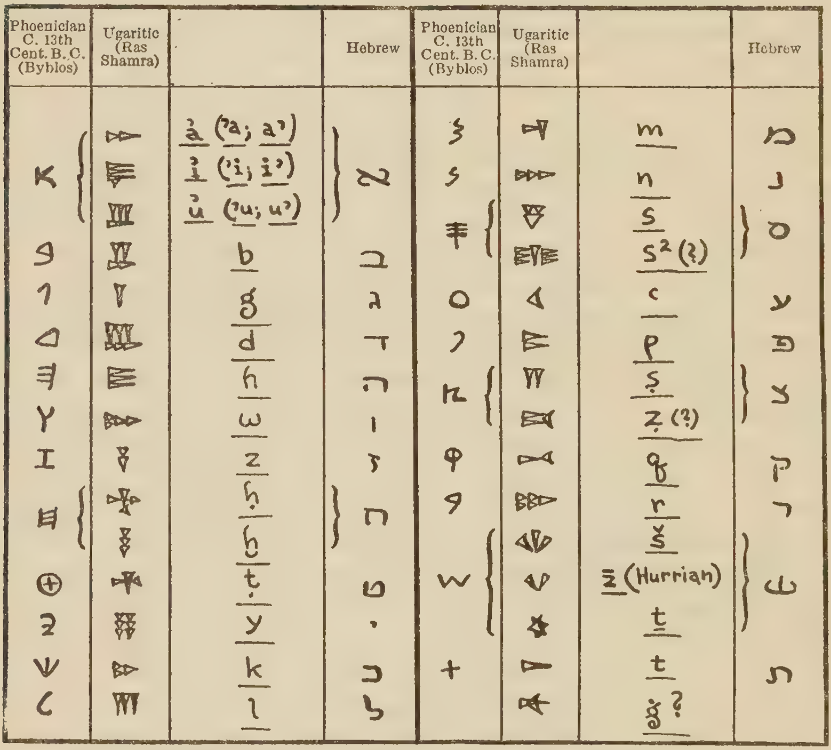
Phoenician C. 13th Cent. B. C. (Byblos)
Ugaritic (Ras Shamra)
Hebrew
Phoenician C. 13th Cent. B. C. (Byblos)
Ugaritic (Ras Shamra)
Hebrew
à ('a; a')
ì ('i; i')
ù ('u; u')
b
g
d
h
w
z
ḥ
ḫ
ṭ
y
k
l
m
n
s
s² (?)
ʿ
p
ṣ
ẓ (?)
q
r
š
ẕ (Hurrian)
ṯ
t
ǵ ?

FIGURE 1.—The Ugaritic alphabet.

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[3] Forms given as they were probably actually pronounced in Ugaritic speech (as nearly as we can judge in keeping with Ugaritic spelling) are put in square brackets.

representing ['ama'idu] "I increased (?)" shows, as do other forms too, that the vowel of the prefix in the derived stems (except the *t*–stems; this is Piel) was [a], and that the stem vowel of the Piel was [i], so that *tkbd* "she honored" was probably pronounced [takabbidu]. The alephs have further served to indicate unexpected sound changes which have occurred in the language of Ugarit, as when the word for "head", which we would expect to be [ra'šu], written *raš*, is found as *riš*.

At times the consonants, too, show unexpected things about the language; it is when we come upon such an unexpected form and are able, in conformity with our other knowledge, to explain why it should be so, that we feel we are not merely reading into the texts what we happen already to know about Semitic, but are correctly interpreting the new evidence. Thus a problem is posed when we find the word "eighteen" written *ṯmn‘šrh*, although the final *h* in the cognate word in Hebrew is always regarded as a vowel letter, and we know there are no vowel letters in Ugaritic. But further consideration shows that even in Hebrew there are indications that this is no ordinary vowel letter but the reflex of some old consonantal sound; the Ugaritic form fits neatly into this understanding. Similarly scholars were unable to understand some of the occurrences of the letter *d*, in such phrases as *rgm d tšm‘*, where *rgm* means "word" and *tšm‘* "you will hear"; but these difficulties disappeared when it was realized that the Semitic sound *ḏ*, which became *z* in Hebrew, had become *d* in Ugaritic (coalescing with Semitic *d* proper), so that some of the *d*-letters were to read as reflexes of Semitic *ḏ*; in this case it is the relative "which" (Hebrew *ze*, Arabic *ḏu*): "any word which you may hear."

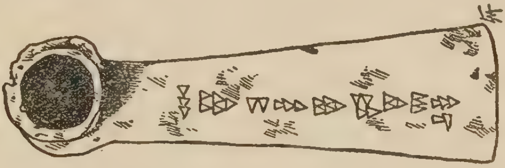

FIGURE 2.—Adze-head found at Ras Shamra. (The inscription in the Ugaritic language reads *ḫrṣn rb khnm* "axe of the chief of priests.") (From Dussaud, Découvertes.)

In this manner the grammar—the structure and system of the language—can be worked out. Many words are interpreted by aid of context, as in the simple case of the word for "sun" *špš* (instead of the usual Semitic *šmš*), which was understood through its occurrence in the phrase *špš wyrḫ* "* * * and moon." But the chief aid to the understanding of the texts and the language, especially in the poems, is the well-known poetic construction of parallelism. It is almost always possible to work out the poetic form even of obscure passages, and if one half of a parallel couplet is understood, we know what to expect in the second half.

THE SOUNDS (PHONOLOGY)

The alphabet of Ugarit shows that the language had most of the consonants which we assume the parent Semitic speech to have had. The sound *ṣ́* (sin) had coalesced with *š* (shin), *ḍ* with *ṣ*, perhaps *ġ* (Arabic ghain) with ʻ (ayin); in historical Phoenician and later Canaanite dialects we find not only these but also other analogous coalescences which have not yet taken place here. The sound *ḏ* has coalesced with *d* (this is the simplest interpretation of their being written similarly), though in Phoenician and Hebrew it moved to *z*. In Aramaic, too, *ḏ* became *d*, but this was over a millennium later.

We have little evidence for the exact pronunciation of these sounds. But we may assume that Semitic *ṯ* (as in English "thing"), although it remained distinct from every other sound in Ugarit, had come to be pronounced somewhat like *s:* the *ṯ*–sign is used in foreign names which probably contained *s*, as in *alṯy* for *Alasiya*, the name of Cyprus.

About the vowels, we may make some deductions. Diphthongs were simplified, as in most Canaanite dialects: the word for "house," Semitic **baytu*, is here written *bt*, and so must have been pronounced [bêtu]. Final short vowels were still preserved, as they were at that time in Canaanite; hence we still have the case-endings as seen above, and the vowels of the indicative and subjunctive verb. The Syrian–Palestinian change of *á* to *ó* did not take place here (as yet?), but there is an interesting change of *a* before aleph (when followed by consonant) to *e*; this change seems also to have taken place in certain Hebrew dialects, and later on in Aramaic. There is also a greater use of the prothetic vowel, in a few words which do not have it in other Semitic languages.

THE WORD-FORMS (MORPHOLOGY)

Ugaritic reveals a relatively early linguistic stage, vestiges of which are barely discernible in such languages as Biblical Hebrew which are modern in comparison. In the verb, the perfect aspect ("tense") has a nominal, descriptive character, and is used chiefly for stative verbs; in Hebrew it can be used for any verb. We have it here in process of spreading; it is not yet generalized. The usual verbal form is the form with prefixed personal element. Here we have two basic tenses, a narrative preterite, and a present. The narrative preterite is the most common, used to relate past events, and probably had the form *yaqtulu* ([yiššaʼu] "he raised," and so on; by its side there seems to have been a short preterite *yaqtul* with consecutive and emphatic force used with proclitic elements like [wa-] "and", [lû-] "indeed." This preterite is preserved in Hebrew as the "imperfect with waw consecutive": as Bergsträsser pointed out long before the Ras Shamra finds, this waw-consecutive form in Hebrew is not a peculiar syntactic construction which gives an imperfect the force of a past tense, but is an actual vestige of an old preterite; the language of Ugarit supplies the missing link of this much discussed grammatical peculiarity.

The present also had the prefixed personal elements , but its vowels were different from those of the preterite. In addition to the indicative, ending in [-u] ([-n] after long vowels), there was a jussive without these endings, and apparently a subjunctive ending in [-a]. There was also an energetic formed by the suffix [-anna] or the like.

The stems of the verb are generally similar to those of Northwest Semitic. There is the common simple stem, known in Hebrew as Qal, and an intensive (Hebrew Piel) with characteristic doubling of the middle consonant of the root. In the causative group there seem, strangely enough, to have been two forms, a vestigial Afel (similar to Aramaic and to Hebrew Hifil), and a Shafel such as is known in Akkadian but not in West Semitic. All these seem to have had their own inner passive forms. In addition there was the Middle ("Inner Active") Nifal, with the same force as in early Hebrew, and a reflexive-reciprocal stem with infixed *-t-*, such as does not exist in Biblical Hebrew (where there is a prefixed *t* stem, the Hithpael) but appears in Moabite and in early Palestinian place-names (e. g., *Elteqô*). There were also some rarer stems, chiefly those used with the weak roots (such as Hebrew Polel). Ugaritic thus does not show affinities with any one language, but has constructions which were preserved or developed here and there by various related dialects.

The weak verbal roots, those with one or more "weak" radical consonants, conform closely with what we would expect at that stage of Northwest Semitic. The verbs which in Biblical Hebrew end in the vowel-letter *-h* (e. g., *ʿālā*(*h*) "he ascended"), still possess in Ugaritic their *y* and *w* consonants (*ʿly* for [*ʿalaya*] "he ascended"), for since final short vowels had not yet been lost the *y* and *w* have not entered into diphthongs.

In the nouns we have, as we might expect, generally the same noun-classes as in the other Semitic languages. The case-endings are preserved; and the rare Hebrew locative ending *-a*(*h*) is now explained from Ugaritic, for we find it here written with consonantal *h* (*šmmh* "heavenward"). The dual, restricted in later dialects to objects which occur in natural pairs, is still used here in its grammatical force.

The pronouns present dialectal and historical points of interest. The third person pronouns are *hwt*, *hyt*, *hmt* [huwatu, hiyati, humatu?]; and we realize that Phoenician *hmt*, Hebrew *hēmā*, are vestiges of a similar pattern. The use of the relative *d* "which" much as in Arabic shows how general this was in Semitic, and sheds light upon its use in the early Byblos dialect of Phoenician, and in early Hebrew (in the form *zu*, *ze*). There is no article, just as there seems to be none in early Phoenician and early Hebrew.

SYNTAX AND LITERARY FORM

The syntax is similar to that of early Northwest Semitic, in spite of the centuries which intervene between Ugaritic and the earliest Phoenician and Hebrew material which we have for comparison. Word order is much the same, and is set in definite forms. In the ordinary sentence the verb precedes the subject, even after most adverbs: [gam yaṣûḥu ʼilu] "Moreover Il cried." But after certain adverbs the order is inverted to subject-verb: [ʻalan(?) šapšu taṣûḥu] "Thereupon Shapsh cried out." There is also a special form subject-object-verb when the subject is in casus pendens (in apposition to the whole object-verb sentence): *šmm šmn tmṭrn nḥlm tlk nbtm* "The heavens—oil they rained; the streams—they flowed with honey." In successive sentence-phrases there are forms of verb consecution in which the first verb may be in one mode and the following ones in another; we are reminded of verb consecution patterns in Hebrew and South Arabic. There is also an enclitic [-ma] (similar to the Akkadian?) which seems to have a conjunctive value between phrases.

The literary form of the poems is typical Semitic. It runs largely in parallel couplets—sets of two short lines, each saying much the same thing—with frequent intrusion of an independent line, especially introductory lines such as "Thus said x." The lines are measured not by the number of syllables in them (as, say, in classical verse), but by the number of stresses (major-stress syllables, as in Hebrew and in English poetry); this type of poetic measure is naturally appealing to English ears. Each short line (stichos) contains usually three stresses, sometimes two or four.

An outstanding feature here is the comparatively high development of strophes—stanza arrangements—over and above the procession of the parallel couplets. There has long been discussion as to how much stanza-arrangement there is in the Bible, particularly in the Psalms, and in the Prophets, especially Isaiah II. Early Semitic epic poetry (e. g., Arabic) shows hardly any strophes, and many scholars denied their existence in the Bible, while others insisted that one could not but find them in Hebrew poetry and recitative. The strophic arrangements which occur here and there in the Ugaritic poems show that we should not be surprised at similar constructions in Hebrew. In general, the poetic touch here is at times similar to the Hebrew, and often we see the same literary and even phraseological background as the Hebrew poets drew upon, witness the similarity to the Bible (especially Amos 1: 3 ff.) of this sentence: [hu(?)m ṯanê dabaḥîma šani'a baʻlu, ṯalâṯa râkibu ʻurapâti] "Indeed two sacrifices Baal hates, three (hates) the Rider of the Clouds." One is impressed by the literary authenticity of the Bible. With all the political, social, and cultural separation of the Hebrews from the Canaanite world, they learned the language of the Canaanites, and with it the culture of its literary tradition. The literature of the Bible rested solidly on the rich background of Canaanite literature, and the form in which it has come down to us is often much closer to the original than we had suspected.

The other outstanding characteristic of the Ugaritic poems is the wealth of repetition and key phrases. There are certain fixed pairs of synonyms which recur frequently in special parts of the poems, or throughout them: *nʿmm wysmm* "pleasant and gracious"; *išt bbhtm* * * * *nblat bhklm* "fire in the houses * * * flames in the palaces"; *rgm* * * * *ṯny* * * * "he said * * * he repeated * * *." Some phrases recur so as to seem like a refrain, giving a strophic character to that section of the poem; in other cases there are stock descriptions (e. g., in supplication scenes, in challenges) which are used whenever the scene occurs. The whole gives a Homeric touch to the mythological poems. It is not common in the Bible, perhaps because of the lack of epic poetry in it; and in the epic prose of the Bible we see a different and perhaps more sophisticated beauty in the simplicity and functional brevity of the telling. But this rich repetition of Ugaritic must be an old feature of primitive poetry, and is known elsewhere in Semitic.

UGARITIC IN THE SEMITIC FAMILY

The Semitic family of languages is one of the best known and most carefully studied of linguistic groups. The criteria of its various divisions are well defined, and it is therefore indicative of how much we have still to learn that several varying opinions have been put forth as to the place of the new-found language of Ugarit within the family. Semitic languages are grouped together into three large divisions: east, northwest, south. The eastern group, Akkadian, is marked off from the other two by many historical developments of its own, but it has certain specific affinities with Canaanite and South Arabic, probably going back to proto-Semitic times when these were perhaps in special contact. The southern group includes North Arabic and South Arabic (with Ethiopic); these agree with the whole northwestern group in several special respects, particularly in the development of the verbal system.

The Northwest Semitic group includes the languages spoken in historical times in Palestine-Syria and, probably, the regions north and east of Syria. The earliest clear material of this stock which we have comes from the north from the turn of the second millennium; it is called Amorite, but the exact character of the dialect is unknown. In Palestine and Syria, throughout the second and first millennium, there were spoken dialects which we call Canaanite. We know something of the pre-Hebrew (South Canaanite) of south Palestine; it was different from the Phoenician of the same time. Later, the Hebrew peoples spread over Palestine and adopted South Canaanite; they had at least two general dialects, a southern Hebrew (the official dialect of Jerusalem) and a northern Hebrew. Across the Jordan we know of one dialect, Moabite, closely related to Hebrew. Meanwhile Phoenician, on the coast north of Palestine, was also Canaanite, but different in several respects; it, too, had several dialects. Of the languages of the far northern coast of Syria we had no information till the Ras Shamra excavations.

During the beginning of the first millennium B. C. there appear from the north and east a new group of dialects, also Northwest Semitic, but different from the Canaanite. These are the Aramaic, which slowly replaced the Canaanite dialects.

In this mass of languages, what are the affinities of Ugaritic? The affinities of Ugaritic with Phoenician and Hebrew are many. In Ugaritic and Phoenician, Semitic *ś* coalesced with *š*; this took place in Aramaic, too, but not in South Canaanite. In Ugaritic and Phoenician and northern Hebrew the diphthongs *ay* and *aw* were simplified to *ê*, *ô*. In Ugaritic and all Canaanite dialects *n* had been regularly assimilated to following consonants, and in Ugaritic and Biblical (southern) Hebrew *n* does not assimilate when it is the third radical of a verb. Ugaritic and Phoenician both replaced the verbal root *ntn* "to give" with the secondarily formed variant *ytn*. The vocabulary is much the same in all, as a comparison between Ugaritic and Hebrew will readily show. Many personal names are the same: the rare name *ʻbdssm*, which occurs in Ras Shamra, appears again in a late Phoenician inscription. Whole phrases are the same: compare Ugaritic *lyhpk ksa mlkk lyṯbr ḫṭ mṯpṭk* "Indeed he will overturn the throne of your reign; he will break the scepter of your rule" with the almost identical phrase from the Phoenician Ahiram inscription, some centuries later, *tḥtsp ḥṭr mšpṭh thtpk ks' mlkh.*[4]

With the Hebrew Bible there are scores of similarities in special uses of words, in phrases, in turns of expression. It may suffice to note but one or two: the use of *bn ydm* (literally "between the hands") in the sense of "back", parallel to *ktp* "shoulder," thus explaining the misunderstood *bên yāḏêḵa* "on your back" of Zechariah 13: 6; the parallel *ʻôlām* "eternity" with *dôr wāḏôr* (Ps. 145: 13, etc.) frequent in Ugarit; the Ugaritic *lḥm bṯlḥnt lḥm štym bkrpnm yn* "eat bread from the tables; drink wine from the goblets" with Biblical phrases using the same words: e. g., Proverbs 9: 5.

In determining the place of Ugaritic among Semitic languages, a few general criteria will serve to narrow the field. Not only does the general body of facts about Ugaritic place it in the Northwest Semitic group, but it also exhibits a special change which is peculiar to that group, the change of initial *w-* to *y-*.[5] Within this group, Ugaritic has certain features peculiar to Canaanite: the masculine plural in *-m* which it shares with Phoenician and Hebrew even against Moabite, and against Aramaic, and against most other Semitic languages; also many vocabulary features, such as *ben* "son" against Aramaic *bar*. There are also interesting affinities between Ugaritic and Akkadian, and between Ugaritic and Aramaic, especially in the verbal system. The only way to decide the historic weight of all these affinities is to determine which are genetic, i. e., due to a primitive period of common development as one language, and which are either old proto-Semitic features which had spread to both languages at that time, or late changes which had spread from one language to the other in historical times. The preterite, which Akkadian and Ugaritic have in contradistinction to the others, is a proto-Semitic form, since we have traces of it in Hebrew and Arabic. The restricted use of the perfect is merely an early stage of its development throughout West Semitic. The stem-system of the verb is of generally Northwest Semitic type, rather than Akkadian. The change of *ḏ* to *d* has no direct connection with the same change in Aramaic, for the latter did not begin till much later. The change of *a* to *e* before aleph is also found in Aramaic, and, under different conditions, in Akkadian; but it also took place in some northern Hebrew dialects, so that it may have been one of those late linguistic changes which spread across dialect and language boundaries. On the other hand, the vocabulary and the bulk of linguistic facts noted above point to a genetic relation with the Canaanite group of Northwest Semitic. It may be that the Amorite language was very similar to Ugaritic, but we know very little of it. In the present state of our knowledge, Ugaritic may best be considered to be North Canaanite.

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[4] Harris, Z. S., A grammar of the Phoenician language, p. 65.

Thus far the finds of Ras Shamra can take us. A considerable literature has already grown around the culture and language of this single mound. But most of the mound is still untouched, and all present conclusions must be held as tentative. The coming years should bring to light much additional information on the society of Ugarit and on its language.

SHORT BIBLIOGRAPHY

Bauer, H.
1936. Die alphabetischen Keilschrifttexte von Ras Shamra (texts).
Dussaud, R.
1937. Les découvertes de Ras Shamra et l'Ancien Testament (archeological and mythological discussion).
Friedrich, J.
1933. Ras Shamra, ein Ueberblick (linguistic and historical discussion). Der Alte Orient, vol. 33.

---

[5] Bergsträsser, G., Hebräische Grammatik I, §17b, §30b.

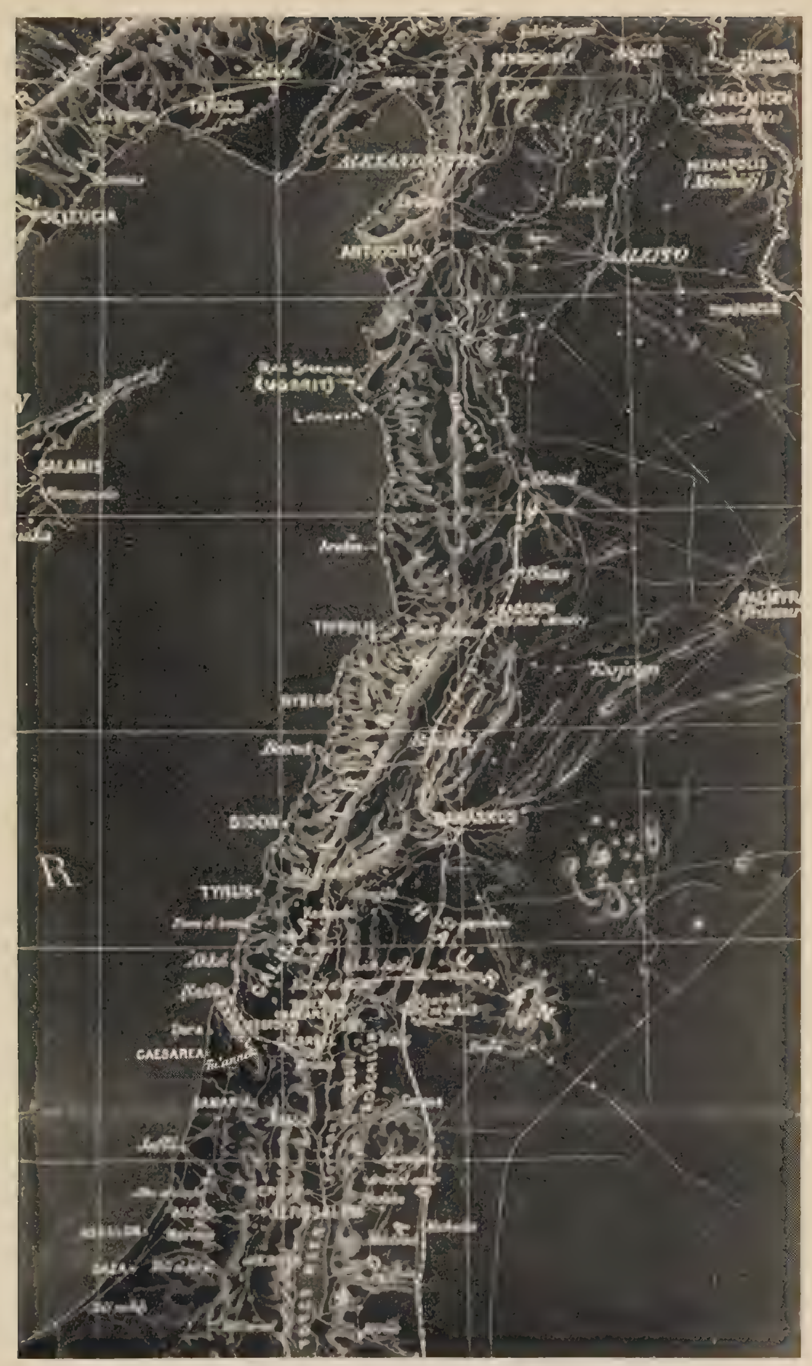
GINSBERG, H. L.
1936. The Ugarit texts (in modern Hebrew: texts and notes, vocabulary). Bialik Foundation, Jerusalem.
MONTGOMERY, J. A., and HARRIS, Z. S.
1935. The Ras Shamra mythological texts (grammar, texts, glossary). Mem. Amer. Philos. Soc., vol. 4.

EXCAVATIONS

SCHAEFFER, C. F. A.
Annually in the journal Syria; brief reports in Illustrated London News. (Cf., especially April 27, 1935.)

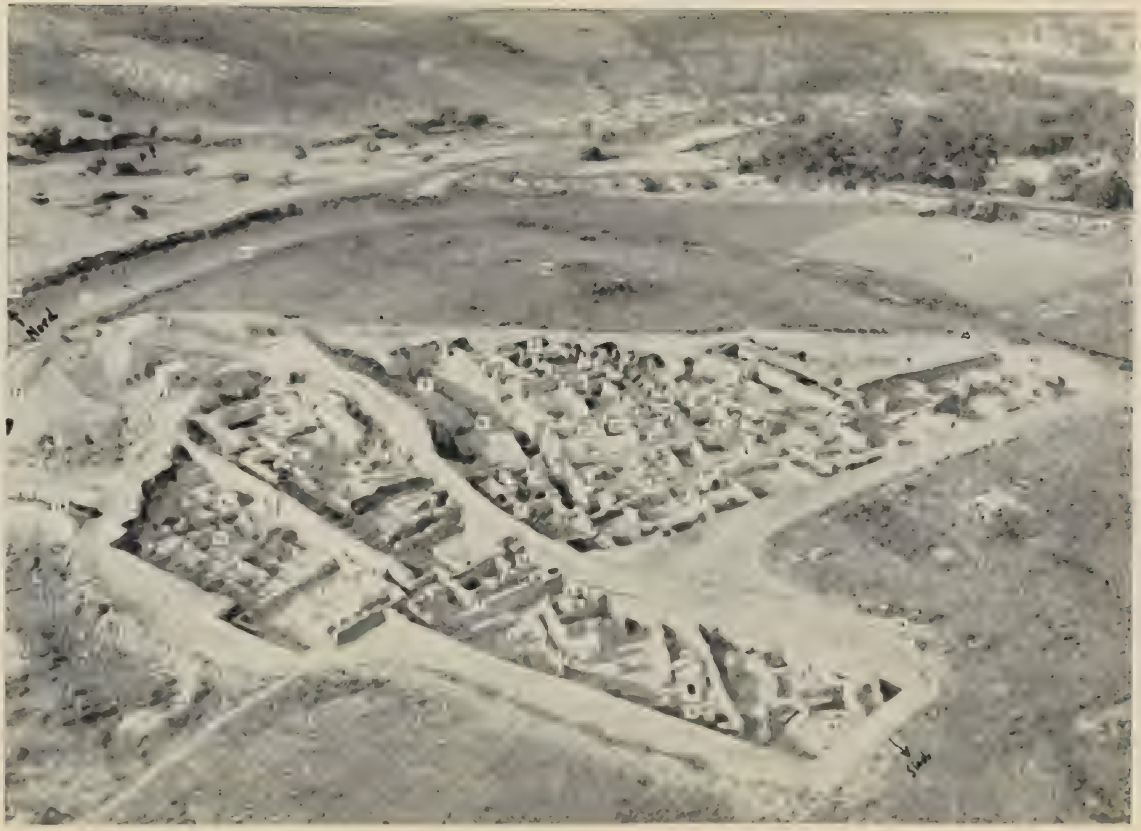
TEXTS

ALBRIGHT, W. F.
1932. The North Canaanite epic of Aleyan Baal and Mot. Journ. Palestine Oriental Soc., pp. 185–208.
1934. The North Canaanite poems of Aleyan Baal. Journ. Palestine Oriental Soc., pp. 101–140.
1936. New Canaanite historical and mythological data. Bull. Amer. Schools Oriental Res., pp. 23–32, Oct.
CANTINEAU, J.
1932. La langue de Ras Shamra. Syria, pp. 164–170.
DHORME, E.
1933. Deux tablettes de Ras Shamra. Syria, pp. 229–237.
EISSFELDT, O.
1932. Baal Zaphon, Zeus Kasios u. der Durchzug der Israeliten.
FRIEDRICH, J.
1933. Zu den drei Aleph-Zeichen des Ras Shamra alphabets. Zeitschr. f. Assyr., pp. 305–313.
GINSBERG, H. L.
1935. The victory of the land god over the sea god. Journ. Palestine Oriental Soc., pp. 327–333.
1936. The rebellion and death of Ba'lu. Orientalia, pp. 161–198.
HARRIS, Z. S.
1935. A Hurrian affricate or sibilant in Ras Shamra. Journ. Amer. Oriental Soc., pp. 95–100.
1937. A conditioned sound change in Ras Shamra. Journ. Amer. Oriental Soc., pp. 151–157.
MONTGOMERY, J. A.
1933–1936. Ras Shamra notes I–VI. Journ. Amer. Oriental Soc.
THUREAU-DANGIN, F.
1931. Vocabulaires de Ras Shamra. Syria, pp. 225–266.
VIROLLEAUD, CH.
Annually in the journal Syria.
1936. La légende phénicienne de Danel, and La légende de Keret. Mission de Ras Shamra, vols. 1, 2.

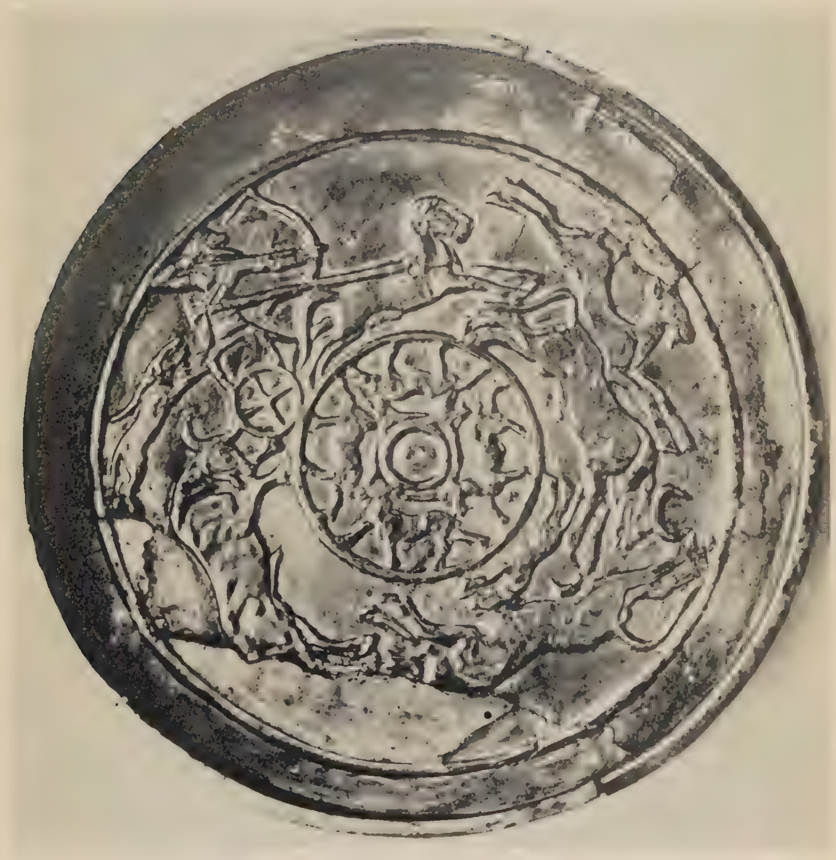

SELEUCIA
ANTIOCHIA
Ras Shamra
(UGARIT)
SALAMIS
TRIPOLIS
BYBLOS
SIDON
TYRUS
DAMASKUS
CAESAREA

THE LOCATION OF RAS SHAMRA (UGARIT).

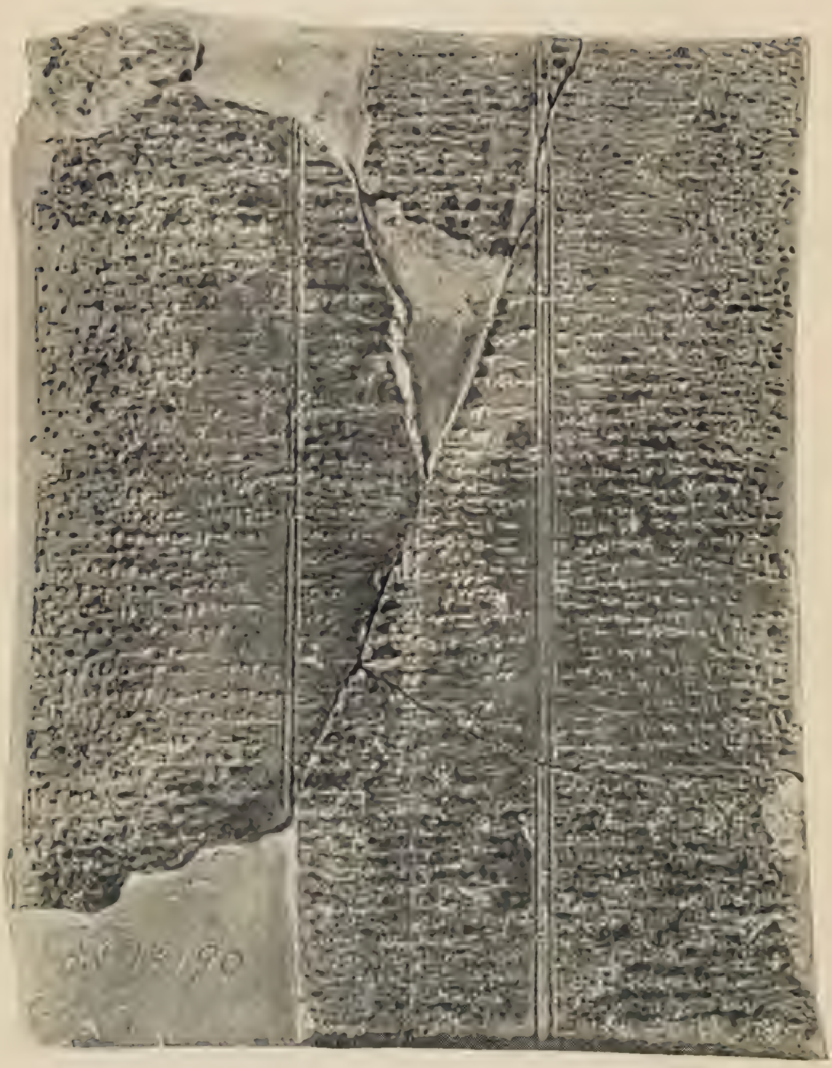
(From Kiepert's map.)



The Excavated Section of Ras Shamra.



PHOENICIAN GOLD PLATE FROM RAS SHAMRA.



A TABLET FROM RAS SHAMRA IN THE UGARITIC ALPHABET: THE LEGEND OF KERET.

BLOOD-GROUPS AND RACE[1]

By J. Millot
Professor at the Sorbonne, Paris

It has been known for a long time that there might exist differences in the blood of animals of different species: Morphological differences connected with the shape and size of the red corpuscles, or chemical differences relating to variations in the respiratory pigment, called haemoglobin. It was also known that individual differences, acquired during life, might appear in the blood: As a result of illness, for instance, certain properties of the blood might be permanently modified by the formation and accumulation of antibodies. At the beginning of this century it was discovered that beside these variations of a zoological or accidental nature, human blood possesses hereditary constitutional differences of an individual and racial importance. The study of these, and especially of their anthropological application, has advanced considerably; at the present moment it almost forms an independent branch of science. The investigations bearing on it are to be counted by thousands, and several scientific periodicals are now exclusively devoted to it.

What are these blood-differences and how were they discovered? Their history is closely associated with blood-transfusion.

Blood is known to consist of a large number of small corpuscles in suspension in a liquid, the plasma. The corpuscles are of two sorts, white (called leucocytes) and red (called erythrocytes) which are much more numerous. Two constituents may also be distinguished in the plasma: A liquid (serum) consisting essentially of a 7-percent solution of salt water, and albuminoid substances in solution, most of which are precipitated if the blood flows out from the organism, producing the well-known phenomenon of coagulation. Under normal conditions the red corpuscles float freely in the plasma, without adhering to each other; but under certain conditions adherence occurs and the erythrocytes collect together in bunches, producing the phenomenon of agglutination. This result can happen both *in vitro*, that is to say, in blood that is kept in glass vessels, and *in vivo*, in a living organism; but their circulation is seriously impeded and very grave accidents may be produced.

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[1] Translated by O. G. S. Crawford, editor of Antiquity, who wishes to thank Prof. Russell Gates for reading the article and correcting some technical errors of translation. Reprinted by permission from Antiquity, vol. 9, no. 36, December 1935.

The idea of blood-transfusion, of injecting foreign blood into a subject weakened by excessive bleeding, is not a new one; we know of undoubted instances occurring as early as the fifteenth century: That of Pope Innocent VIII, for example. The results of these early transfusions, made mostly with the blood of heifers or lambs, were so disastrous that in the seventeenth century the operation was made illegal by an act of parliament passed in Paris. The cause of these failures was partly discovered in 1874, when Landois showed that the serum of an animal of one species agglutinates the red corpuscles of animals of other species; that is to say, that if one mixes the blood of two animals of different species, there ensues a general clumping of their corpuscles: That has been called hetero-agglutination. At that date it was thought that agglutination only took place between the bloods of different species. Accordingly transfusions were then made again but only with human blood; the results were good in certain cases but still disastrous in others. That was the state of affairs when, about 1900, several doctors observed fortuitously that the serum of certain sick people agglutinated the red corpuscles of healthy patients. This phenomenon, which was called iso-agglutination, was at first regarded as indicating a pathological condition; but researches were continued and Landsteiner proved that, when the blood of two perfectly healthy people was mixed, agglutination was produced or not according to the patients who were the subject of the experiment. He concluded from his experiments, on the one hand that iso-agglutination can exist in a normal human being, on the other hand that the iso-agglutinating properties are not the same in all human beings, and that these should, from this point of view, be divided into several categories or groups. That is the double discovery of fundamental importance for which Landsteiner was awarded the Nobel prize—a discovery whose origin is to be found in the great volume of research devoted for a quarter of a century to the serological properties of the blood.

How should the facts brought to light by Landsteiner be interpreted? The simplest explanation, and the one most usually given at the present moment, is that iso-agglutination results from the reciprocal action of two kinds of substances whose chemical nature, however, remains completely unknown; the one called agglutinogen is contained in the red corpuscles, the other, or agglutinin, is in the serum. Analysis has shown that there are at least two different agglutinogens, conventionally called A and B[2] and capable of being present in the red corpuscles either singly (A or B) or together (AB), or not at all (O); certain individuals therefore have only A, and others have B, and others both agglutinogens; while yet others are totally devoid of either. It is this which is described somewhat inaccurately (but which has found its way into scientific parlance) as the existence in the human species of four blood-groups—group A, group B, group AB, and group O, this last containing neither A nor B.

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[2] In this deliberately simplified description, we are not taking into account either agglutinogens or accessory agglutinins.

To the agglutinogens of the corpuscles correspond agglutinins in the serum which are distinguished by the Greek letters α (or anti-A) and β (or anti-B). The same blood never possesses agglutinins active in the presence of their opposites; or in other words, the serum of a given individual never agglutinates its own corpuscles—a result which in fact would make circulation, and consequently life, impossible. Accordingly the serum of bloods belonging to group A contains, not agglutinin α which agglutinates A, but agglutinin β; and it is the serum of group B which contains agglutinin α. The group AB, possessor of two agglutinogens, can never have agglutinins, whilst group O possesses at the same time both α and β. From this it follows that the complete formulas of the blood-groups are $A\beta$, $B\alpha$, ABO, $O\alpha\beta$. This nomenclature is the one usually adopted, but two others, those of Jansky and Moss, are also in use.[3]

If one brings together the blood of two people belonging to the same group there is no result—the blood mixes normally. If on the other hand one brings together blood samples from groups A and B, α will react with A, β with B, and agglutination will ensue.[4]

In the light of these facts we now know how to practice transfusion without risk of accident; it is enough to establish to which group the patient belongs, and to obtain the blood from a donor belonging to the same group as himself. Nothing is easier, for in the big towns there have come into existence specialized institutes whence, by telephoning, one can immediately obtain a "donor" of the required type. In actual fact, the agglutinins are only active when concentrated, and those of the donor, diluted in the blood of the receiver, appear practically without effect; it results that one can always transfuse blood of group O (universal donor) into a wounded patient, whatever his group, without serious results; and that, conversely, a subject of group AB can receive without harm any blood whatever (universal receiver).

Human beings, therefore, are divided into four groups, according to the serological properties of their blood. These preliminary explanations having been given, let us see what main characteristics are revealed by the reactions of agglutination; after which we will consider the applications of the results to different subjects, particularly those of an anthropological nature.

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[3] The groups are indicated by Roman figures; according to Jansky $O=I$, $A=II$, $B=III$, $AB=IV$; according to Moss $AB=I$, $A=II$, $B=III$, $O=IV$.

[4] The hypothesis of agglutinins and agglutinogens is a convenient explanation of the facts; but does it correspond with reality? Are there definite chemical bodies involved? No doubt we have to reckon only with special properties which may be common to many different substances, under certain well-defined physical conditions (Mendes—Correa).

It is a fundamental fact that blood properties have a remarkable permanence. Their individual stability may even be regarded as absolute; a man never changes his group under any circumstances whatever. We already have observations covering 25 years, and we know that age never modifies the reactions, nor does any physiological condition. Illness has no effect, nor have treatments of the most varied kind, in spite of what may have been said to the contrary. X-rays, like those of radium, or repeated anaesthesia, produce no effect. Lastly, the group is not changed even after a transfusion from the blood of another group; and the case is actually recorded of a subject of group *AB* (universal receiver) having undergone 75 transfusions with blood from each of the four groups without suffering any modification of his own blood.

A second characteristic of blood properties is the precocious manner in which they are differentiated. The agglutinogens appear before the agglutinins. They are sometimes discoverable in the second month of embryonic life. One can in any case always detect them during the last weeks preceding birth, and so plainly that it is always possible, normally, to know to what group a new-born child belongs.

If blood properties are fixed and precocious, they do not manifest the same degree of strength in all subjects. Agglutinins, like agglutinogens, differ in strength according to individuals, race, and age. It has been recorded, for example, that the power of agglutinins, always very weak at birth, increased up to 30 years of age, to decrease after 40; and that it was greater amongst Malays than amongst Europeans.

The fact of belonging to a given group is a hereditary characteristic. It would be impossible here to give even a rapid outline of the mechanism of heredity. What is essential is to know that in a child no agglutinogen can appear which is not present in the blood of one or other of its parents. If the father and mother belong to group *A*, all the children may belong to group *A*; if they belong to group *O*, all the children will belong to group *O*; if the parents do not belong to the same group—if, for example, one is *A* and the other *B*—the children will differ and be *A*, *B*, *AB*, or *O*.[5] Recognition of these facts has resulted in curious applications of them. It has made it possible, for instance, to restore to their respective mothers newly born infants which had been mixed up immediately after birth. Above all it has been used in medico-legal practice to investigate paternity.

Attempts have been made to establish a connection between blood properties and other morphological or physiological characters of the organism, such as stature, skull-form, pigmentation, hair, age of onset of puberty, etc. All these attempts appear to have failed, the different correlations announced having all been more or less falsified by the results, in the light of more extended observations. Thus, it had been stated that in Sweden the majority of group *B* subjects were brachycephalic; but this has not been generally established, and it may be regarded as a mere coincidence. Some doctors believed they could detect a relationship between the serological properties of blood and the liability to certain maladies, such as infectious fevers, cancer, etc. Victims of tuberculosis, for instance, belonged most frequently to group *A*, whilst members of group *B* suffered from a noticeable weakness of the nervous system, and amongst them psychoses were more often observed and criminals most common. But existing observations are not nearly numerous enough to justify such conclusions.

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[5] It may be added that according to Bernstein (1925) and Snyder (1925) blood groups inherit as 3 multiple allelomorphs corresponding to the agglutinogens, *A* and *B* being dominant in association with a similar recessive *R*, and not as 2 independent pairs of factors, as was formerly thought.

Lastly there is the important belief that the reactions of iso-agglutination are not peculiar to the human species. They have been found in several other mammals. In most they appear to be much weaker and less constant than in man, and to result from different agglutinogens; on the other hand, human agglutinogens and agglutinins are also found in the anthropoid apes, gorillas, chimpanzees, orang-utangs and gibbons. It follows that one could transfuse the blood of a chimpanzee into a man of the same group without ill effect, whilst transfusion of human group *B* blood would have serious consequences.

These few general observations are enough to demonstrate the great interest, from many points of view, of agglutinative phenomena and the researches which they have inspired. We shall next see that a knowledge of this subject is of the greatest importance for anthropologists, and that the fact of belonging to a given group—a fact, as we have seen, independent of age, sex, and every other physiological condition—seems, on the other hand, to be a very definite function of race.

It had been noticed ever since the first investigations, that the proportions of the different groups maintained a remarkable constancy in a given population, amongst the Germans or the Italians, for instance. But the suggestion (due to MM. L. and H. Hirszfeld) that there might be a relation between the anthropological content and the distribution of agglutinogens was not put forward until later. Being attached during the war to the medical service of the Army of the East, these biologists had opportunities of examining the serological properties of the blood of a large number of soldiers or civilians belonging to very different races. They established three categories: One marked by a high percentage of subjects of group *A* and a low percentage of *B*, and including the majority of European races (European type); a second showing on the contrary a high percentage of *B* and a low one of *A*, comprising Mongoloids and Ethiopians (Asio-

African type); and a last category containing approximately equal quantities of *A* and *B*, comprising Russians, Turks, Arabs, and Jews (intermediate type). This discovery, published in 1919, gave rise to a considerable number of investigations, producing an enormous mass of documents of varying merit, and emphasized the great ethnological interest of blood groups. It would need many pages to give a complete account of the results, and we must therefore confine ourselves here to describing a few of the essential features.

Hirszfeld thought he could conveniently synthesize these features by calculating for each race a "biochemical index," obtained by dividing the percentage of *A* by the percentage of *B*, that is to say, by establishing the proportionate fraction $\frac{A+AB}{B+AB}$. If out of 100 subjects of a race one found 40 *A*, 10 *B*, and 5 *AB*, the index would be $\frac{40+5}{10+5}=\frac{45}{15}=3$. The biochemical index for the European type thus fell between 2.5 and 4.5, the index of the Asio-African type between 0.5 and 1.1, and the index of the intermediate type between 1.3 and 1.8.

This index has been much used. But the most recent researches have shown, on the one hand that the sero-ethnic types established by Hirszfeld were not exact enough, on the other that the biochemical index was open to serious criticism; in actual fact, all races in which the proportion of *A* is equal to that of *B*, whatever might be their absolute value, would have a similar index, equal to *I*, whatever the number of the *O*'s or of the *AB*'s, which is obviously unsatisfactory.

Many other formulae have been proposed to replace that of Hirszfeld, but without offering any clear advantages over it. On the other hand successful use has been made of tables, which have proved most instructive.

The examination of such tables enables us, following Ottenberg, to distinguish a certain number of quite well marked sero-ethnic types. One such is remarkable for its extreme poverty in both *A* and *B*, that is to say it includes almost exclusively only the subject of group *O*. It comprises the American Indians, the Filipinos, and most of the Eskimos of pure race; it is called the Americo-Pacific type.

A second type, adjacent, rather deficient in *B*, but richer in *A*, is represented by the Australians (Australian type). A third, again poor in *B*, but very rich in *A*, includes all western European type. A fourth type is marked by a moderate proportion of *A* and *B*, and includes the Negroes, Melanesians, southern Asiatics (Annamites, Javanese) and is called the Afro-Malay or Afro-south-Asiatic type. A fifth, embracing the Near Easterns (Turks, Persians, Armenians, Arabs) as well as Russians and Czechs, has a moderate proportion of *B* and a high percentage of *A* (intermediate type). A sixth has a very high proportion of *A* with a considerable but lower proportion of *B*;

called Hunan, after the name of the Chinese province, it includes, besides that region, the Japanese, a part of the Koreans, and in Europe the Poles, Ukrainians and Hungarians. Lastly, a seventh type, poor in *A*, but the richest of all in *B*, comprises all the Hindus, the north Chinese, the Manchurians, and in Europe the Gipsies (Indo-Manchurian type).

Such in outline is the actual classification of races according to the serological properties of their blood. Some anthropologists have criticized it severely, going even so far as to deny that blood-groups have any ethnological value at all. They claim that from a study of it one can deduce no valid argument bearing on the relationship of races. They point out, for instance, that Hindus and Europeans have wholly dissimilar blood, whereas there are good reasons for supposing that both are descended from a common stock; on the other hand, the Lapps, who are of Asiatic origin and very different from the Norwegians, are made to belong with them to the European type. They argue also that Jews occur in almost all the categories, as much amongst Afro-Malays as in Europe (German Jews), amongst the Intermediates (Spanish Jews) or amongst those of the Hunan type (Rumanian Jews and Jews of Beirut). These objections have very little weight. It is now agreed that Hindus and Europeans are much less closely connected than was formerly supposed, on the strength of linguistic evidence wrongly interpreted. The Lapps have very irregular blood-formulae, and they are sufficiently intermarried with their Scandinavian neighbors to make it not at all surprising that their original blood should have been modified and now approximates to that of Europeans. Finally, we may now regard it as certain that the Jews do not constitute a true race, but a group of communities which are ethnically distinct and united primarily by a common bond of religion. It may be added that if Grove, for instance, found very different blood-formulae amongst the different Ainu tribes, that was because he did not guard sufficiently against sources of error (consanguinity), which invalidate his statistics.

On the other hand, many accurate observations, as Snyder has emphasized, confirm the real ethnic value of the reactions of agglutination, and show that populations of different blood can live side by side for centuries in the same country without their serological properties undergoing any modification, if there is no intermarriage. Thus the index of the Japanese and that of the Ainus is very different, although these two races have been neighbors in Japan for several millennia. The facts are particularly striking in the United States; the three great races which have lived there on the same territory for 300 years still retain widely different indices—the Indians having one of 9.5; the whites, 3.6; and the blacks 1.4. Hungary provides another choice example, because in that country are brought together colonies which are ethnically very different—Hungarians from the east; Gipsies, probably of Hindu origin; and Germans of a date before the eighteenth century—the study of their blood shows, in the plainest possible fashion, that the Germans of Hungary react like those of Germany, whilst the Gipsies are of the same type as the Hindus, and that the Hungarians come close to the Turks—results agreeing entirely with what we know from other sources.

We may conclude that blood properties provide us with a genuinely valuable means of revealing the purity of a race, and that they owe their importance to the fact that they are at once strictly hereditary and as independent as possible of environmental influences.

Certain anthropologists have gone further and tried to extract from serology information about the origin of races. The first theory of this kind is that of Hirszfeld, who was struck by observing that, as one passes from western Europe to eastern Asia, the proportion of *A* diminishes and that of *B* increases. The fact is indisputable. *A* passes from 45 percent amongst the Norwegians to 27 amongst the Manchus. In the case of *B*, the change is particularly striking. One meets in turn with 12 to 14 percent in western Europe; 20 to 23 percent in the Balkans; 25 percent in the Turks and Arabs; 34 to 49 percent amongst the Indo-Chinese; Chinese and Hindus. Hirszfeld thought that from these facts he could infer a dual origin for the human race. There would have existed, according to his ideas, two human stocks, one having group *A* in its blood and coming from northern and western Europe, the other, with group *B*, coming from the east, perhaps from India. The two stocks having mingled in the regions where they came in contact would have given birth to an intermediate type; the *B* element having, for instance, been introduced into Europe with the different oriental and Mongol invasions. This view is entirely hypothetical. And while most anthropologists at the moment believe that the agglutinogens *A* and *B* may well have come into existence separately and in different regions of the earth, they will not admit a dual origin for the human race. It is known, in fact, that entirely new morphological, physiological, or chemical characteristics may, in conformity with the laws of heredity, appear quite suddenly in a species. The phenomenon is called mutation, and numerous instances have been recorded in animal breeding. According to Bernstein and Snyder, the serological properties of the blood might thus have appeared as a mutation, and the human species be derived from a single stem which originally lacked both agglutinogens and agglutinins. One of the principal arguments in favor of this view is that the living representatives of races regarded as pure, but on the way to extinction, have group *O* either exclusively or at least dominant. Thus out of 112 Navahos examined by Rife, 111 belonged to group *O* and only 1 to group *A*. It would seem then that we may regard this group

O as primitive. Starting with this primary human blood, there would have become differentiated the agglutinogen *A* in Europe, then the agglutinogen *B* in Asia; doubtless there would also have been a supplementary mutation of *A* in the Far East, responsible for the Hunan group. The supposition that group *A* is older than group *B* rests on the fact that there are several races, such as the Australians, who have group *A* but not group *B*, whilst none are known to have group *B* without group *A*. According to this view, the fact that pure-blooded Indians are all of group *O* would prove that they became separated from the Mongolian peoples before the appearance of any blood mutation; and the fact that group *A* but not group *B* occurs amongst the Australians would be evidence of their having been isolated from their stock during the period that elapsed between the two mutations.

These views are strongly in favor at the moment. Prof. J. B. S. Haldane expounded them eloquently in a discourse before the Royal Institution some years ago.[6] We must, however, face the fact that they are largely hypothetical, and personally I can hardly admit them. Why, for instance, should the Senegalese have 19 percent of *B*, when they do not appear to have any trace of Mongolian admixture? One is driven to assume an independent mutation of *B* in Africa, which merely complicates matters. But above all the fact that human agglutinins and agglutinogens are found amongst the anthropoid apes seems to us to have a very important bearing on the problem, and to show in the clearest possible way that blood-groups have existed for a very long time indeed. Their recent simultaneous origin in monkeys and men is, in fact, most improbable; is it not more natural to suppose that the common ancestors already possessed agglutinogens? We will confine ourselves to saying, finally, that if a character can appear by mutation, it can also disappear by the same process; and it should be remembered that the majority of the mutations observed in the course of animal-breeding are regressive, and consist in the loss of a structure or of a differentiation, not in the appearance of a new character. Is it not more satisfactory to regard the Redskins, for example, as Mongoloids who have lost agglutinogen *B* than to suppose that they left Asia before the appearance of the mutation?

We may conclude that, while the study of the reaction of agglutination may not be able of itself to solve any anthropological problem, and while no complete racial classification can be founded upon it so that up to a point it may have betrayed the somewhat fantastic expectations aroused at the start, yet it does provide means of appraisement which are of great interest, complementing and checking those derived from other sources. No serious anthropological inquiry can in future dispense with it.

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[6] See note at end, No. 1.

Let us state, in conclusion, that the agglutinative properties are not peculiar to the blood. They are found precisely the same in the different secretions—milk, saliva, gastric juice, bile, sperm; they are even found in the minced tissue. They are a constitutional feature of the whole organism. They are obtained from the blood merely because they are easier to detect there.

NOTE.—The following articles in English deal with the same subject:

1. Prehistory in the Light of Genetics; a discourse delivered at the Royal Institution on Friday, February 20, 1931. Printed in The Inequality of Man, and other essays, by J. B. S. Haldane pp. 63–77 (blood-groups, pp. 63–70), London, Chatto and Windus, 1932.
2. Blood-Groups and Physiognomy of British Columbia Coastal Indians, by R. Ruggles Gates and George E. Darby. Journ. Roy. Anthrop. Inst., 1934, vol. 64, pp. 23–44.
3. Eskimo Blood-Groups and Physiognomy, by R. Ruggles Gates. Man, 1935, No. 36.
4. Gates. Heredity in Man, chapter 9. (Constable, London.)
5. The Distribution of the Blood-Groups, by Allison Davis, Sociol. Rev., 1935, vol. 27; January, pp. 19–34; April, pp. 183–200 (with list of books cited).
6. The Relation of Blood-Groups to Race and Some Particulars of the Southwest Pacific, by H. J. T. Bijlmer. Journ. Roy. Anthrop. Inst., 1935, vol. 65, pp. 123–31.

EARLY CHINESE CULTURES AND THEIR DEVELOPMENT: A NEW WORKING-HYPOTHESIS[1]

By Wolfram Eberhard

In regard to the origin and manner of growth of the Chinese civilization, numerous theories have been propounded, by ethnologists on the one hand, by sinologists on the other. None of them, however, it must be admitted, has so far met with much favor in either camp.

Ethnologists in general hestitate to commit themselves in regard to any of the higher civilizations; for without a thoroughgoing familiarity with its language and its entire literature, they find it most difficult to form any accurate judgment about it. Unfortunately, the majority of workers in such a field are obliged to shape their opinions at second hand, through the medium of such translations as may be available. They therefore incur the danger of basing their conclusions on faulty renderings by the translators. Hence, even the latest works treating of China from the ethnological point of view, although they often contain matter of the highest interest, are certain to be regarded by the sinologists as standing in need of further corroboration. In their adoption of this attitude they are thoroughly justified, and for so doing we owe them warm thanks; since it is only as we are stimulated by their criticisms that we can hope to make any progress at all.

On the other hand, there are the theories advanced by the sinologists themselves. These we may range in two major groups. Of these, one holds that about the third millennium B. C. a Western people with great natural abilities and a high type of culture migrated to China and settled there, first in the valley of the Wei River and then in that of the Huang Ho (the Yellow River). From these regions they gradually spread their civilization among their more backward neighbors, and so created the germ of the later China.

The second of the two types of views maintained by the sinologists holds the Chinese to be autochthonous, and their civilization in consequence to have been developed independently in China itself, without any foreign aid of importance. According to this theory, the primitive Chinese shaped their culture themselves and then were able, through natural increase in numbers and by a process of absorption, to spread it gradually over the whole of what is today the Chinese area.

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[1] Translated by permission from the Proceedings of the Ethnological Society (Tagungsbericht der Gesellschaft für Völkerkunde), second session, in Leipzig, 1936. Translated by C. W. Bishop.

Ethnologists have looked with distrust on both the latter groups of theories, and these have indeed been unable to find any real support. Everything that we know about the way in which civilizations have grown up in other parts of the world forbids us to believe that in China alone the process of culture-building was as simple as is implied by either of the two above views. Moreover, the books written by their advocates would give their readers the impression that the Chinese civilization of the second and first millenniums before our era had already acquired a uniformity of character in no way essentially different from that which it has today. From this belief has sprung the strange notion that the Chinese civilization displays a stability unexampled elsewhere, and with a total lack of any tendency toward evolutionary change.

Now, to the trained ethnologist who travels through the interior of China it quickly becomes apparent that there exist at the present day in that country, often even in quite small areas, very great differences in culture. Such differences can only be explained by the assumption that this or that region has held fast with varying degrees of conservatism to its own ancient customs and individual peculiarities. These obviously go back to very old local cultures. The latter must have been even more strongly marked 2,000 or 3,000 years ago than is the case today.[2]

Here at the outset we must recognize clearly that the sinologists who maintain either of the two above-mentioned theories have acted on the following principle; that is, they have made indiscriminate use of all statements in the Chinese literature which bear in any way upon cultural development, without first considering to what particular part of China any given statement may refer. Now, nearly every such passage states explicitly the place of which it speaks; but such information has not so far been taken into account. Yet no matter what the results sought for, statements of this sort are the very first to which attention should be paid. The same applies with equal force to the study of linguistics. The still youthful science of Chinese philology has tried to reconstruct the pronunciation of Old and Middle Chinese. In so doing, however, it has tacitly assumed that throughout the country a given character was pronounced in the same way and has passed through a precisely similar course of development. Yet in opposition to this quite unwarranted assumption are the facts that even at the present day the Chinese spoken in various parts of the country is pronounced in very different ways; and that, moreover, the old dictionaries give long lists of such dialectical forms. I need only mention here, by way of illustration, the word *ch'ü*, *hsü*, or *ch'iu*, signifying in modern Chinese "place", "cave", or "hill", but which goes back originally to an old word belonging to the Coast Culture (the latter we shall discuss at some length later on)[3] and which there had the meaning of "market place." The distribution of those place names in which this word forms an element is somewhat narrowly restricted; reference to the *Ch'un-ch'iu* and the *Tso-chuan* shows that it appears only in a region where the Coast Culture may be supposed to have exerted influence. Another word belonging to the same culture group appears to be *lang*, meaning "youth," "man." A word of the Southern Culture seems to be *yin*, common in titles and often signifying something like "leader." The study of such dialect-words has so far only just been begun by a very few sinologists, but has not yet been carried to a definite conclusion.[4]

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[2] Regarding these survivals of ancient local cultures, recognizable even today, see W. Eberhard: On the structure of a central Chinese local culture (Zur Struktur einermittelchinesischen Lokalkultur), Artibus Asiae, vol. 7, 1937.

PART I

In my investigations I have begun to include the use of such sources of information as those just mentioned. Those from the most different periods must be employed. The task is still in its infancy. No one man can hope to carry it out successfully; for it involves nothing less than the careful reexamination of the entire body of the Chinese literature, art, and all other cultural phenomena. For the present, only brief reference will be made to the results already attained, and a working-hypothesis will be set forth which appears to me to accord well with both the historical and the archeological evidence thus far available. In this hypothesis there will be no effort to go back to any ultimate beginnings or even to the origins of the basic cultures involved, but only to a cultural stage already "late" in the ethnological sense and which, historically speaking, covers roughly the period 2500–500 B. C.

The theory that the Chinese civilization was single in its origin can no longer be upheld. Since even today, after a development extending over 2,000 years, there may still be recognized several more or less distinct local cultures, the latter must also have been present in times earlier still. Through their interaction it was that the civilization which we know as Chinese assumed form. The fixing of the territorial limits and the distinguishing characteristics of these local cultures is consequently one of the most important tasks in the whole field of Chinese ethnology.

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[3] It is also possible that this word may have belonged to the Coast Culture only in a secondary sense, but originally to the Southern Culture; on this point further investigation is needed.

[4] It is to be hoped that the above suggestion may stimulate someone to undertake this study in earnest.

1. We may, I think, distinguish the following local cultures. In the first place comes a Northern Culture.[5] This extended, within the region which we now call China (its extension outside that area we shall not consider here, since for that purpose the Chinese sources are insufficient), over the present province of Hopei, northern and eastern Shansi, and northern Shantung as far as a line passing somewhere near the sacred mountain of T'ai Shan.

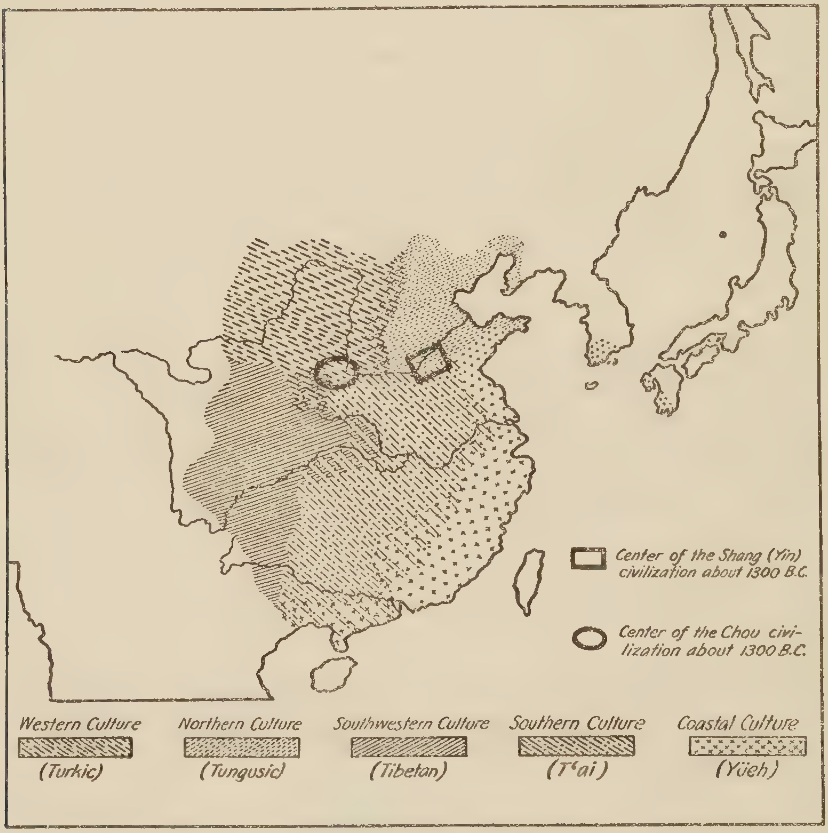
Center of the Shang (Yin) civilization about 1300 B.C.
Center of the Chou civilization about 1300 B.C.
Western Culture (Turkic)
Northern Culture (Tungusic)
Southwestern Culture (Tibetan)
Southern Culture (T'ai)
Coastal Culture (Yüeh)

FIGURE 1.—Approximate limits of the basic Chinese cultures about 2000 B. C.

That this culture may well have been proto-Tungusic, ethnically speaking, several indications unite to suggest. Among these is its possession of a form of shamanism, practiced by magicians or medicinemen who during the latter part of the first millennium B. C. played an especially noteworthy part. Significant also in this connection is that veneration of the bear which sometimes appears. So too is the occurrence on the Shang (Yin) Dynasty oracle-bones of a certain folkname of a neighboring people who, under the form Jurjen, are perhaps to be identified as the ancestors of the later Manchus.

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[5] The terms used here to designate these various early cultures are applied on purely arbitrary grounds; personally, I should prefer to distinguish them by the names of their bearers.

It is possible, perhaps even probable, that this Northern Culture, for all its proto-Tungusic characteristics, contained a strong Palaeasiatic element also. Excavations on Neolithic sites in northern China show that the New Stone Age population of that area, insofar as it possessed this particular type of culture, lived in pit dwellings about a man's height in depth and with their tops reaching only a little way above ground. These people, moreover, made use even in far later times of bone arrow points. For clothing they must originally have employed fur garments. Further, this culture had myths about the fox,[6] in which that animal plays the role both of a "trickster" and of a semidivine being. Noteworthy also was the great freedom permitted to women. This reached such a degree, indeed, that it is possible to speak of something in the nature of a matriarchate; there seems likewise to have existed a custom of guest prostitution like that found today among certain Siberian tribes. Among the myths belonging to this culture may also be that of the exposure of the hero while still an infant and his protection by various beasts (Hou Ch'i myth). In regard to this last attribution, however, I am not entirely satisfied; for here enters the question of borrowings from the Western Culture (to be discussed below), since this particular type of myth displays in many of its details distinct solar elements. Head flattening seems also to have been practised, at least occasionally, although whether it was really a characteristic trait is not sure. Traces of it appear, however, even today, in northern China; for there, longheaded children are regarded as ugly and a child's head is therefore kept in a cushioned ring which probably causes a certain amount of head deformation. Whether the dead were disposed of by means of platform burial is also uncertain. This Northern Culture was in its primitive form quite devoid of anything in the way of agriculture, and is accordingly to be reckoned among the higher types of hunting and food-gathering.

2. West of the preceding was what we shall term here the Western Culture. Many things about this unite to indicate that its possessors were people of Turkic stock, doubtless very early intermingled with other groups. To it we must ascribe a strong element of pastoral nomadism with a rigidly organized patriarchate and a religion consisting of the worship of the heavenly bodies. Among further characteristics we may reckon the use of the horse, with a rite of horse-sacrifice. Clothing was probably of skin. The dwelling, originally a round tent, was later widely adopted as a type of habitation throughout eastern Asia. Graves were marked by tumuli or mounds, likewise

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[6] Concerning the details of these myths see W. Eberhard: Typen chinesischer Marchen (F. F. Communications, No. 120, Helsinki, 1937); for the texts, ibid., Chinese fairytales, London, 1937.

round in form. Boats, when used at all, were of hide or of inflated skins. The typical musical instrument was an earthenware drum; later (perhaps through foreign influence) there appeared stringed instruments. The levirate and associated practices seem to have been common. The part of China occupied by this culture appears to have been the northern fringe of Shensi, western Shansi, and part of Kansu.

3. Adjoining this Western Culture on the south was what may be termed the Southwestern Culture. This had its center in what is today the province of Szechuan, and its possessors we can with certainty identify as the Tanguts—a people in all probability of Tibetan stock. This culture must in earlier times have had a greater extension eastward, in one direction to Honan, in another to Hupei and Hunan; while it also sometimes reached southward as far as Tongking. Among nearer areas later penetrated by this culture were Yünnan and Tibet.

Here too, horse breeding played an important part, along with pastoral nomadism and sheep raising. Cremation was perhaps typical, as likewise were polyandry and the couvade. It is however difficult to determine just what were its distinctive features; for there survive, from the period when it played a part of importance for the whole of China, no traditions which might supply us with clues; while so far no excavations have been undertaken on sites indubitably belonging to it. In later times, moreover, it lay a little to one side of the main current of Chinese development, so that there exist very few literary references to help us.

4. To the east, in the heart of the present Chinese area, was the Southern or Ch'u Culture, so called from the ancient kingdom of Ch'u, which had its nucleus in the present province of Hupei. Next to it and lying along the coast was the Coastal or Yüeh Culture, named after the old state of Yüeh. Of these two cultures we shall speak later on in more detail. For the moment we may turn to the last of the early cultures, one whose existence has thus far been scarcely more than hypothetically established, and to which only a very few traits can be assigned as definitely typical. It is, however, of extraordinary importance to a correct understanding of the cultural situation in southern and central China. This is the Li Culture, whose possessors were in my opinion Austroasiatics. That we must reckon with the presence of people of that stock in China is rendered the more certain by the fact that even to this day their remnants survive in the province of Kueichow. This in itself justifies us in including them in our enumeration. There are, moreover, many other indications that in earlier times they played a role of greater importance than we should at first have suspected. Their culture can only have been that of a very backward hill-people who were food gatherers, not growers; at most

they can have had only a very primitive form of agriculture, carried on by burning clearings in the forest and then cultivating them with the aid of digging-sticks. We must, however, exercise great caution in trying to assign to them any typical cultural traits whatsoever; since by the time when they first come within the purview of history, their culture had already been so deeply overlaid and so greatly modified by those both of the south and of the coast that it never appears before us in its pure and unmixed state.[7]

The study of these two cultures, the Southern and the Coastal, discloses that they share certain characteristics which can only be explained as due to much mixture and overlaying and which are probably, in part at least, the result of contacts with the Li Culture. As long, however, as no researches have as yet been carried out along these particular lines, I do not care to commit myself in regard to them.

5. In central China, especially in what is now the Province of Hupei, the Li Culture has been overlaid by that which we have called the Southern. This becomes evident when we observe that the bearers of the latter culture were by habit valley dwellers, while the Li people, as food gatherers, preferred living in the hills. In this way it is quite possible for two such different groups to live close to each other in the same district, with only a very slow intermingling of their two culture patterns. We have instances of just such a state of affairs even today in southern China and especially in Yünnan.

The extent of the Southern Culture must, however, have been far greater than the above would suggest. Its former existence may with certainty be ascribed to southern and western Honan, to western Shantung, to Anhui, parts of Kiangsu, Kiangsi, and Kuangtung, and also to the whole of Hunan. Its bearers seem to have belonged to that T'ai stock still to be found in scattered groups over South China and Farther India. They appear to have had a wet-rice culture, associated with irrigation and the keeping of water buffaloes and cattle. Their former extension can be clearly detected in the distribution of myths dealing with the origin of rice and of cattle, and of others in which the ox appears as a beast-helper (cf. the stories of the Cinderella and the Swan Maiden type). To this Southern Culture, too, belong the myths which portray the river-god in the form of an ox.

Typical of the same culture seem also to be the terraced fields of rammed earth (*t'ai*), later made of rough stonework; offerings of grain (later of bread) cast upon the rivers; and an agrarian spring festival. Among musical instruments appears especially the mouth-organ or jew's-harp class. There was also the plow, or perhaps rather its forerunner, a two-pointed spade especially adapted for working in flooded fields. The religion seems to have been a combination of ancestor-worship and of a fertility cult with offerings of swine. The latter are in contrast to those of horses and cattle which characterized the Western Culture and to the different type of cattle-sacrifice found in the Coastal Culture. Among myths seems to have been one which told of the separation of Heaven and Earth, regarded as a wedded pair. This, however, is not quite certain; this particular myth may have belonged originally to the more primitive culture of the Li people.

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[7] Here belongs the problem of the Miao and the Yao, two aboriginal peoples of South China; into this, however, we cannot enter here. There seem nevertheless to be definite indications that while these peoples differ from each other, they are both Austroasiatics, influenced in different ways—the Miao mainly by the T'ai peoples, the Yao on the other hand rather by the Coastal or Yüeh Culture. There was perhaps still another ethnic element in southern China, the Negrito; a dark-skinned group of short stature, still living in some parts of Malaya and the Philippine Islands. So far, however, the evidence is not sufficiently definite to warrant our setting them up as a separate group in China.

6. The Coastal Culture is by far the most important of all the early ones, especially when we take into consideration regions outside of China itself but adjacent thereto. Its bearers were a people called the Yüeh, who, it would seem, were essentially Indonesians. They appear as living by the sea, with whose ways they were very familiar; and they had a well-developed art of navigation. Chinese sources state that they had also settled in southern Korea as well as in the Chinese province of Shantung; while recent investigations concerning Japan suggest that in that country, too, the Yüeh people had settled rather densely in certain areas.

The center of the Yüeh Culture lay in the province of Chekiang, in the neighborhood of the sacred mountain Kuei-chi, about which revolve all their origin-myths. In regard to this culture the written records mention so many characteristic traits, of the most diverse origin, that it can clearly be shown not to have had a single origin but to have been composed of elements from a variety of sources. This leads us to suspect that all the other early cultures enumerated above would also show a similar multiple origin, were it not for the fact that the available literary evidence in regard to them is far more scanty in amount. On account of this defect in our knowledge, however, we are unable to determine the true degree of their complexity. Hence we inevitably tend to oversimplify them and to consider them as derived from a single source. This, of course, includes the Northern and the Southern Cultures already mentioned, in each of which we can detect traces of several still older and quite distinct cultures. In the Coastal Culture this becomes at once definitely apparent. For in it we find, together with culture-elements quite compatible with the character of a seafaring coastal people, others apparently better suited to hill dwellers, and also still a third group more in conformity with the culture pattern of a plains-dwelling folk with a more advanced type of agriculture.

As typical of this Coastal Culture we may mention the following traits: A developed navigation; the practice of holding boat races, with its outgrowth the dragon-boat festival; the use of bronze drums decorated in a way showing connection with that rite; and the concept of the dragon as river-god. A feature of the spring festivals characterizing this culture was a ceremony of wading through streams (a rite apparently associated with the dragon concept); and myths which speak of a dragon-mother, who gives birth to dragons. Closely allied to this group of myths was one which had a "Moses" motif (a child is cast away upon the waters in a chest and grows up to become a hero). There has also survived a group of myths of brother-and-sister marriage, and likewise of a deluge. In the same complex again are others, of marriage with a dog (in some instances, with a frog). The dog seems to have been venerated as the tribal ancestor; and there was also a frog cult connected with a fecundity cult. Straw images of dogs were buried with the dead, or were used as charms in cases of illness. Magician priests played an important role, and women took a part in cult and ritual practices which would have been quite impossible in the Western Culture. Boys and girls were consecrated to a divinity or to a sacred mountain, either as actual sacrifices or at least with an accompanying prohibition of marriage. Elements of this culture were the worship of serpents, of sacred mountains (the latter destined to develop into important temple festivals), and of certain trees. Cattle were sacrificed on all occasions, their horns being preserved as holy objects. In some instances there were bullfights which terminated in the immolation of the defeated bull. Also customary was the holding of wrestling matches, perhaps derived from the bullfights or at least connected with them; for the contestants wore masks bearing the horns of cattle. Funeral feasts were celebrated, and the bones of the dead were given a second burial after the flesh had decayed from them. First-born children were sometimes killed and eaten by their parents (on this practice see the following paragraph). The hills were thought to be peopled by mountain spirits and one-legged gobblins, in contrast to the ideas about fox spirits prevalent in the Northern Culture.

Young people, perhaps after having undergone a rite of initiation, were free to select their own mates, instead of having their marriages arranged for them by go-betweens; the token of betrothal was the exchange of girdles by the interested parties. Marriages were concluded at the spring and autumn festivals. For some time thereafter the wife continued to live with her parents and there receive visits from her husband; during this period she enjoyed great freedom. After the birth of her first child, however, she went to live with her husband, to whom she was thenceforth expected to remain true; connected with this custom, in all probability, was the one just mentioned, of the slaying of the first-born child. Sometimes, however, the husband went to live with the family of his wife until he had paid for her by working for her parents.

Clothing seems to have consisted of narrow widths of cloth, two of which were sewn together with an opening at the seam through which the head was thrust. Thus originated the earliest form of the so-called "kimono" type of garment, typical of all eastern Asia, in marked contrast to the fitted and tailored clothing found in the Northern and Western Cultures. The loin cloth (the Japanese *fundoshi*) also perhaps belongs to the Coastal Culture; for it is still occasionally to be seen in the island of Hainan, where, however, it seems not to have been a very ancient feature. Possibly also bark cloth was made. Tattooing in various patterns, perhaps totemic in nature,[8] as also the staining of the teeth black, were likewise customary. Another practice sometimes mentioned was that described as "drinking through the nose." This is a special way of drinking certain stimulants by sucking them through a tube of some sort, by way of the nose. Bathing in rivers was quite general, as was also the practice of pouring warm water over the body (cf. the latter practice in Japan). Cockfighting was characteristic. An important arm was the crossbow, just as the Southern Culture is distinguished by its use of poisoned weapons. The horse was entirely unknown. Walled towns, originally absent, appeared later, beyond much doubt as a foreign intrusion. In their place, communal houses were typical—long pile dwellings beneath whose elevated floors were kept the domestic animals. Cultivation seems to have been carried on in fields cleared by fire, with the aid of the digging-stick and the spade; the latter of these implements, however, perhaps did not come into use until later. In later times also rice-growing was adopted from the Southern Culture by that of the coast, through which it eventually traveled still farther, even to Japan. Notched sticks (tallies) and knotted cords (quipus) as means of recording events or sending messages receive such frequent mention that they must have been typical of this Coastal Culture. The sun was regarded as feminine, the moon as masculine.

The traits just enumerated are obviously so heterogeneous that they cannot possibly have originated in any one culture. Such a condition seems most likely to have been due to the superposition of the real Austronesian bearers of this culture, in the hilly country on the one hand upon the Li people, in the plains on the other upon the possessors of the Southern Culture; from both of these they would in time have absorbed certain culture elements. Something of this sort, at least, appears the most probable solution of the problem. Perhaps, however, it will eventually appear that we must seek in this connection still another early culture, whose very existence we as yet hardly suspect.

The entire structure, in fact, which I have tried to erect is so far merely an experimental one, certain to need rebuilding and carrying on to completion. However in its main outlines—i. e., the listing of the six basic cultures out of which has developed the historical Chinese civilization—I feel convinced that it will stand. What we have tried to depict here is the cultural situation which existed in China during something like 2,000 years before our era (2500–500 B. C.). We must not suppose that during the earlier part of this period the mutual interpenetrations and interminglings of these early cultures were as marked as they became farther along in the same period, to say nothing of still later times. Material gathered from the latter it seems to me quite permissible to use in connection with our study, since it comes from just those regions where the early cultures had not yet been so deeply submerged by the type of civilization then prevailing in the Chinese area proper.[9]

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[8] Perhaps these same patterns were also displayed on the garments, as F. Rumpf has suggested in the case of the Japanese. The designs on the clothing seem usually to have been worked on them in cross stitch. Even today among some aboriginal peoples of southern China, certain designs on the clothing are typical of certain families or other social groups.

PART 2

I shall now try to show how, in my opinion, out of the above early cultures there developed the historical Chinese civilization. The process as I depict it, I wish to emphasize, is so far nothing more than a far-reaching hypothesis. The attempt has, however, already been made to bring the scheme which I have worked out by the aid of the early historical and archeological material now available into conformity with the one drawn up for the Farther Indian and the Oceanic Cultures by Professor Heine-Geldern. Should the latter's theory prove correct—at least in its general outlines—then we may expect to find on Chinese soil also evidences of those early cultures that he has postulated. We have, as a result of our preliminary discussions, already reached a broad agreement. Further attempts have been made—by Dr. Rumpf (Berlin) on the one hand and, along somewhat different lines, by Dr. Oka (Vienna) on the other—to explain the development of the Japanese culture. The result of such preliminary discussions has been, moreover, to show that in this way far-reaching conclusions may be attained.

1. The oldest culture that has as yet been clearly distinguished on Chinese soil is the one called, from its type-station, the Yang Shao. With this are grouped certain others, often very limited in area, perhaps in part contemporary with it, whether they be slightly earlier or slightly later. This culture contains, in my opinion, elements derived from the Western Culture; this, for instance, it is, perhaps, which is responsible for that unmistakable western Asiatic influence shown by its painted pottery. Possibly, indeed, it will prove to have been the case that there had already settled in the Ordos region Scythians or some such people, who were the carriers of these elements. In this event we shall have to suppose that very early exchanges took place

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[9] A work in which the evidence in support of the views here outlined is given is in course of preparation; but for some references on the subject see the Arch. f. Relig. Wiss., vol. 32, p. 366, and vol. 33, p. 332.

between the Western Culture and that of the Scythians. However, such an early appearance of the Scythians in the area in question has not yet been proved.[10] A second component of the Yang Shao culture is to be found in the Northern Culture, from which it took its pit dwellings, its use of bone in the manufacture of implements, and the common gray pottery decorated with cord or mat impressions. Still a third source is to be found in the Southern Culture, from which came rice growing, already proved for the Yang Shao; to it we may add also the sedentary mode of life. Whether the Southwestern Culture likewise played a part in the formation of the Yang Shao is not yet clear; but in any event it seems not to have made its influence as strongly felt as that of the others named.

2. At somewhere about the same time that the Yang Shao culture was taking shape in western China or only a very little later, there appeared in what is now the province of Shantung, in eastern China, the Lung Shan (sometimes called Ch'êng Tzŭ Yai) culture, with its characteristic pottery of black earthenware. This we do not as yet know very well; but we can say with assurance that in it likewise there appears a strong element of the Northern Culture—a stronger one, indeed, than that which we have just found in the Yang Shao. With this there also appears an element derived from one or other of the two southern cultures. That of Lung Shan is in any case very much mixed, and is a direct first step in the formation of the culture of the Shang people, which we have now to consider.

3. The Shang culture is the oldest in China for which we have as yet both historical and archeological evidence. In this also is to be found a marked element of the Northern Culture, just as we saw in that of the Yang Shao; but this seems to be slowly losing its strength among the Shangs. Far more powerful was the influence exerted by the Southern Culture, with its rice growing, its cattle breeding, and its production of silk. Most clearly significant in this connection is the influence which has been exerted by the speech. For these Shang people, as the inscriptions which have been discovered testify, already spoke a language very similar on the one hand to that of the present-day Chinese, while on the other it was most closely related, among those of all these early cultures, to the speech of the T'ai peoples. The same inscriptions also speak of clans, whose names we recognize as those of ones which existed, later on, in the Ch'u kingdom previously mentioned.

Shang agricultural implements were probably of wood, since none of their remains have thus far been found. Recent Chinese investigations have, however, made it very probable that the Shangs had the two-pointed spade characteristic, like the above-named traits, of the Southern Culture. This type of implement was long retained in eastern China until somewhere around the middle of the first millennium before our era, there appeared the plow, possibly as a development of the spade. The difficulty about this last point lies only in this; that the plow seems first to have been known in western China, where we as yet hear nothing of the existence of an implement of the spade class. Possibly this may mean that the plow has been introduced into China from abroad. At all events it soon spread through the north and then over the center and south of China. The presence of survivals among the agricultural processes in use even today shows that Yüeh influence on the Shang culture was also by no means negligible. The many cowry shells, objects of mother-of-pearl, and bones of the whale that have been found suggest that the Shang people carried on trade with the east coast, where, according to tradition, the Yüeh were already seated. The influence of the latter on the Shangs is, I believe, likewise shown by the "kimono" cut of their clothing and especially by the style of the decoration found on their bronzes.

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[10] The question to what extent these people, whether Scythians or not, were Indo-Europeans, and how far northern influences, Siberian or even Nordic European, are to be taken into consideration, forms another field of investigation which has thus far yielded no definite results. In post-Christian times, however, blond people appear in western China.

Finally, this Shang Culture also contained an element derived from the Western Culture, and which seems to have been growing stronger with the passage of time. While the Shang religion appears to have been at first only agrarian in its character and so to be explained as due to the influence of the Southern Culture, there appears in it later on a worship of sacred mountains which may well be ascribed to the Yüeh Culture; while later still we can trace a change to an astral type of religion, as indicated by the inscriptions on the oracle bones. For the latter, we may now assert with confidence, the bones of oxen were used at first. We must infer, therefore, that the use of chicken bones and still later of their eggs, for oracular purposes, was typical of one or other of the southern cultures, whether of that of the south itself or that of the coast; and that, further, between these oracles and those drawn from the bones of oxen there exists some sort of connection. As yet, however, we are not well enough informed as to the nature of the cattle sacrifice in use among the Shangs to try to bring its ox-bone type of oracle into direct relationship with the ox cult and the ox sacrifice of the Coast Culture. Later, in place of ox bones, the shells of tortoises were employed by the Shangs. That the latter should thus have come to prefer tortoise shells is only explicable on the ground that, as stated by later texts, they saw in the rounded upper shell (carapace) a symbol of the vault of Heaven, and in the flat lower one (plastron; the part used in consulting the oracle) that of the plain of Earth. Thus already we find here evidence of astrological speculations like those which became especially conspicuous later on, in the culture of the Chou people (to be considered later), under the stimulus of the predominantly astral religion of the latter. This we can hardly explain otherwise than as due to the influence of the religion of the Western Culture, definitely astral in character. As the texts repeatedly declare, the greatest enemies of the Shangs were a people who dwelt just to the west of them and who were known as the Chiangs. This name was that later applied to the Tanguts and thus suggests that its original bearers belonged to our Southwestern Culture. Today, thanks to archeological excavations and the inscriptions which these have yielded, we are able to state the approximate extent of the Shang kingdom and its associated culture. These occupied only a comparatively small area, comprised in southern Hopei, northern and eastern Honan, and western Shantung. The Chiangs, though, as we have just seen, they belonged to the Southwestern Culture, must at that time still have extended eastward as far as portions of Honan. This conclusion is by no means as absurd as might at first appear.

4. Let us now glance at what had been going on in the meantime in the west. There, after the disappearance of the Yang Shao Culture, the Turkic stocks, bearers of the Western Culture, had been coming more and more prominently into the foreground, probably because they themselves were in turn being hard pressed by their northern neighbors. The latter we can now confidently call Scythians. The cultural changes which followed the disappearance of the Yang Shao Culture are unfortunately hard to interpret in the light of such scanty archeological evidence as we thus far have. We must, however, think of a slow transition as going on during the bronze age, through the continuous action of long-lasting and widely spreading western European influences. The bringers of these new occidental culture elements must have wandered eastward and there intermingled freely with the possessors of the Southwestern Culture. As a result of such interminglings (affected somewhat by even earlier but weakly felt intrusions from the Southern Culture), there was formed a new Western Culture, that of the Chous. The vocabulary of the latter, according to evidence presented by recent Chinese investigations, contained a Turkic element. The Chous it was who brought with them into China an astral type of religion and the idea of strongly centralized chieftainships. Around 1000 B. C. they succeeded in subduing the Shang kingdom and its culture. The latter, strongly agrarian in character and with a well-marked development of handicrafts but which had already long been urbanized, was in consequence deeply overlaid by the culture thus brought with them by the Chous. These had a strong tradition of pastoral nomadism, although before their conquest of the Shangs they had become agriculturists themselves and only retained the memory of having once been a pastoral people. They found themselves forced to adopt much of the Shang civilization. For example, they took over the Shang system of writing with but few modifications, and were in consequence compelled slowly to abandon the very language that they spoke They likewise took over the Shang bronze technique, to-

gether with its style of ornamentation. In short, they borrowed nearly all the features of the Shang civilization. It was not until about the middle of the first millennium before our era that they began to lay aside the Shang culture traits in favor of their own.

They had begun this process of culture borrowing long before their conquest of the Shang kingdom; and they continued it for several centuries thereafter. In its course they had followed a precedent often seen in the subjugation of an agrarian culture by a predominantly pastoral and nomad one; that is to say, the Chous, as conquerors, became a ruling class. In bringing this about, they had settled groups of their own people at points of strategic importance all through the country, to govern the lower class, composed of the Shang people who occupied the region. There thus grew up as a characteristic of the Chou culture a feudal system—the only one, in the circumstances, by which a numerous conquered people could be held in subjection. The nature of this feudal system and the way in which it imposed itself upon the old agrarian culture of the Shangs explain also the following fact. As we learn from the texts again, in the first millennium B. C. the population which considered itself as "Chinese," viz, the ruling group of the Chous and that part of the conquered element which had come into the closest contact with the latter, was sparsely distributed, in widely separated settlements and city states, over a region otherwise peopled by folk whom they distinguished as "barbarians" and who belonged to the old agrarian culture. Outside the territory under Chou control, again, were still other peoples who belonged to one or another of the earlier cultures. These, in the first millennium B. C. at all events, occupied scattered enclaves throughout the entire region under discussion.[11] Further significant of this condition is the fact that not until around the seventh century B. C. did the distinction between "Chinese" and "barbarians" appear. By that time, as a consequence of this imposition of the Chou culture upon that of the Shangs, there had begun to develop a civilization which we may call Chinese and whose possessors had begun to feel themselves as being somehow different and superior to their neighbors, to whom they had in reality originally been so closely related. During Shang times the neighboring peoples had been denoted by a word which meant something like "land" or "region" and which only later took on the significance of "barbarian."

The above-described fundamental differences between the Chou and the Shang cultures also explain the sociological contrasts between the two. In that of the Shangs, predominantly agricultural in nature and hence basically allied to the Southern Culture, there had been as in all agrarian cultures with an organization of small peasant holdings instead of great landed estates, no necessity for slave labor. In its place, however, such cultures have often demanded large numbers of human victims for sacrifice in connection with fertility rites. To this fact we may attribute the extreme frequency of human sacrifices and the absence of slave owning and slave labor during Shang times. Along with this (and here we are reminded of what has been said in connection with the Southern and the Coastal Cultures) went the existance of a priestly caste of great power and importance.

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[11] See in regard to this the references given in the Zeitschr. f. Ethnol., vol. 63, p. 425.

In contrast to all this we may set the lack, among the Chous as among so many pastoral peoples, of rites accompanied by human sacrifice, their place being taken by great offerings of animals. The Chous, as a people with a tradition of pastoralism, may well have made use of slaves originally for watching their flocks and herds. They had moreover a keen appreciation, acquired in the course of their wandering mode of life, of the advantages inherent in a disciplined government. Hence they used their captives of war not as human sacrifices but as servants. Since, however, they had already given up their pastoral economy before their conquest of the Shang kingdom but had not, on the other hand, gone on to develop one of great landed estates, and had but little knowledge of land management, they left the latter to their subjects. Such slaves as they had they employed merely for watching and other similar services—a clear remembrance of their original manner of using slaves during their former pastoral life.[12] This instance will perhaps suffice to show how our new working-hypothesis may be used in the solution of particular problems, and how by its use we may reach a clearer understanding of many phenomena. We may also draw an inference of a somewhat similar sort from the fact that the Shangs sacrificed in temples, but the Chous on the other hand in the open air—another significant cultural distinction.

As an objection to our theory that the Chinese civilization grew up out of the interaction of various local cultures, it may be urged that in the first millennium B. C. the art of the entire Chinese area was obviously uniform in style. This is, however, not fundamental. It can be shown that the callings of certain families were exercised over wide areas and during long periods of time in accordance with hereditary traditions. For instance, there still lived in Lo-yang as late as the fifth century A. D. a group of potters who claimed descent from the ancient Shang population and who thus seem to have been carrying on a particular craft for some 1,500 years. We also find references to the existence of families of bronze casters; these suggest that, speaking generally, bronze vessels were in all probability made by individuals or families with whom the process was an inherited tradition. Particular pieces, obviously provincial in origin, will have to be explained as the work of local families.

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[12] The rite of "following in death," occasionally met with in the Chou culture, differs somewhat from the above-mentioned human sacrifices of the Shangs; it is a practice by no means unknown among pastoral peoples.

In the above historical sketch we have omitted any reference to a Hsia Dynasty or a Hsia Culture. This we have done deliberately. For everything that we have in the way of references to that dynasty is in part so vague and questionable, in part so general and so devoid of ethnological significance (since we cannot work with purely political statements), that it does not allow us to draw a picture of a Hsia Culture. Excavations carried on at sites alleged to have been occupied by the ancient Hsias (in southwestern Shansi) have so far brought to light only remains of the Neolithic Period. Hence we do not know whether there was in reality a Hsia Culture at all. If there was, however, its center, according to our working hypothesis, must have been at the focal point where the Northern, the Western, and the Southern Cultures came together. It would thus have differed from the Lung Shan and the Shang Cultures in the absence of any element derived from the Southwestern Culture. All this is, however, so far purely speculative, and has no real basis in ascertained fact. We shall have to await new discoveries before we can form any conclusions in regard to a Hsia Culture. For the present, any attempt to discuss it would be premature.

PART 3

In the view presented here, then, the civilization which we call "Chinese" has not been developed from any single source but has been the product of a mixture and union of several quite distinct early local cultures. That of the Shangs, which we may safely term proto-Chinese, took form in the region where the Northern, the Southern, and the Coastal Cultures all met. It was finally overlaid by the intrusive Chou Culture, which in its turn originated at the point where the Western, Northern, and Southwestern Cultures impinged on one another. In this way there came into being the Chinese civilization properly so-called, with all those distinguishing characteristics which it bears even to this day.

Our study suggests many questions into which we have not gone at all. For instance, we have made no effort to decide to which one of the early cultures we must ascribe the various forms of stone hatchets found on Chinese Neolithic sites. Neither have we so much as mentioned the extent to which the art of the Yüeh Culture may have influenced the decorative style found on the Shang Dynasty bronzes. Nor have we raised the question as to which of these early cultures is to be attributed the practice of mother-right on the one hand and of father-right on the other. All such points we shall have to omit. In my opinion, however, our study has already brought out enough to show that these cultures were themselves in no sense unitary structures. Not until we have additional evidence can we, in my belief, ascribe to one of them the custom of mother-right and deny it to another. It seems to me that such details will very probably become clear to us in the light of further study. For the present I think it better to postpone our investigations in such specialized fields. First of all we must clearly determine the nature of the early cultures and define them more exactly than we have yet been able to do. Until then, we should not try to deal with these further questions, important though their solution undoubtedly is. Before we undertake to do so, we must learn the true nature of the original relationship among the Austroasiatic, the Austronesian, the Tibeto-Burman, and the Sino-T'ai groups of languages. Then only shall we be in a position to proceed further with our study.

Should the working-hypotheses suggested here hold good, they will also provide us with a method of drawing fresh deductions as to the early ethnology of Farther India and Indonesia. These deductions will rest upon a foundation similar to that afforded by the hypothesis which Professor Heine-Geldern has already sought to establish. They will likewise give us a new picture of early Japan. According to the old theory, the origin of the Japanese people was to be explained as the result of a fusion of Tungus from the north, of Ainu of uncertain affinities, and of Malays from the south. But now investigations seem to have made it clear that the Japanese culture was already in existence before the period of the Malayan wanderings had commenced. The Malayan theory has weaknesses in several other respects also. It would seem, indeed, that the question might be far better explained if in place of the Malays we were to put the Yüeh people. For the features which, in both culture and in language, have been regarded as "Malayan" seem rather to indicate the presence in Japan of influences emanating from the Yüeh Culture. Nor can the Tungus theory be any longer permitted to stand.

Further discussion of such points as the foregoing would, however, be outside the scope of our present inquiry. I hope, in the course of a cooperative study which is to be undertaken together with a group of specialists, to reach a satisfactory explanation of such questions and to obtain for Japan and Farther India also working-hypotheses in harmony with the one which I have set forth above in respect to China.

Finally, the question goes much further, for it poses problems much more far reaching still. Of these, one is that raised by the existence of numerous parallels between the Central American civilizations on the one hand and those of eastern Asia and Farther India on the other. There has already appeared a whole group of American culture-elements which may have reached America partly from the northern portions of the Asiatic continent and partly through direct contacts with the Chinese coast. All such features must in any case be considered from the point of view which we have been discussing. Their study, thus undertaken, seems likely to lead to results of very great importance.

ORIGIN AND EARLY DIFFUSION OF THE TRACTION PLOW*

By Carl Whiting Bishop
Freer Gallery of Art, Washington

[With 4 plates]

The earlier efforts of mankind to assure an abundance of food consisted largely in the performance of magical ceremonies, frequently orgiastic in character. It is sometimes forgotten that such methods, even after regular cultivation had come into being, long continued to survive in close association with what we should consider more rational procedures. Yet this is a fact which we need to keep steadily in mind while we try to work out the early history of the traction plow, which here refers to plows drawn by animals, especially those of the ox-kind.

Certain members of the genus *Panicum*—the millets—seem to have been the first cereals actually cultivated. These, grown with the aid of the hoe and the digging-stick under the *jhūm* system of tillage, had spread over a large part of the Eastern Hemisphere before the close of Neolithic times. Under this system, small plots of ground are cleared, often with the aid of fire, and are then tilled for 2 or 3 years until their fertility has been exhausted, when they are abandoned.

It was not, however, the growing of millet but rather that of wheat and barley which became associated with the development and diffusion of true agriculture. The first steps in this process had already been taken long before the dawn of history—possibly even before the end of the Epipalaeolithic period.[1] Hand in hand with the greater stabilization thus gradually brought about in the food supply there went a corresponding increase of efficiency in the instruments employed in its production. Of these, the hoe and the pick have never undergone improvement save in matters of detail; in principle they remain today what they were in prehistoric times. To regard either of them as *directly* ancestral to the plow is to be misled by superficial resemblances in nonessentials.[2] For example, the hoe handle can scarcely have been the origin of the plow-beam; for the latter, as we shall see, appears to have been absent in the earlier plows, its place being taken by a rope.

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*Reprinted by permission from Antiquity, September 1936.

[1] Curwen, E. Cecil, Agriculture and the flint sickle in Palestine, Antiquity, vol. 9, p. 62, 1935.

[2] In the Mém. Soc. Royale des Antiquaires du Nord, 1902, Sophus Müller (Charrue, joug, et mors, p. 39) points out that the earlier Egyptian hoes differ more from the contemporary plows than do the later ones. Berthold Laufer (Jade, 1912, p. 48) and Paul Leser (Entstehung und Verbreitung des Pfluges, 1931, p. 558 and note 29) both regard the hoe and the plow as possessing different histories.

It was quite otherwise with that archaic implement, the digging-stick. This in time developed into the foot-plow, which assumed a variety of forms, either curved or else bent at an obtuse angle, and provided with a rest against which the cultivator pressed with his foot. Possibly the "shoe-last celts," characteristic of the Central European culture known as Danubian I, were in some instances at least the shares of prehistoric foot-plows.[3] In regions as far apart as Ireland, China, and even Peru, men using implements of this class have worked in pairs abreast, walking backward, their belief being that in this way they can accomplish much more than when acting indepedently.[4] Such instruments are still employed in parts of the British Isles, the Sudan, the Far East, and elsewhere.

A further step in the direction of more effective tillage was the application of the principle of traction. By this method, while one individual pushed the implement, one or more others pulled it with cords.[5] This practice likewise attained a wide distribution. It appears to have existed at one time or another in nearly every part of the north temperate zone of the Old World. Perhaps certain large leaf-shaped stone implements found in northern China were the shares of such primitive man-drawn plows.[6] Instruments operated on this principle were used until lately in parts of Europe; and they still survive in discontinuous and usually backward areas from North Africa and South Arabia right across to the extreme east of Asia.

The substitution of animal for human power marked the final step in the evolution of the true traction plow. This change seems most likely to have been initiated through the operation of ideas which we should consider the reverse of utilitarian, but which to earlier peoples seemed rational enough.

That the bull and the cow have often been regarded as embodiments and even as gods of fertility is well known. Such beliefs seem to have been more especially prevalent in those lands where wheat and barley were cultivated in antiquity. It was perhaps the wish to enlist the magical fertilizing force believed to inhere in the ox-kind rather than to secure the aid of their physical strength which led to their association with the operations of early agriculture. On Egyptian reliefs both bulls and cows are seen employed in traction, and they are still so used in many lands. The use of the ox could only have been a later development. Castration, of bulls as well as of men, probably originated as a feature of those orgiastic fertility cults so common in the ancient Near East; it symbolized a dedicatory sacrifice—a species of ritualistic synecdoche. Only after the practice had become established could men have learned that animals thus treated are thereby rendered more docile.[7]

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[3] Childe, V. Gordon, The dawn of European civilization, pp. 66, 172, 1925: cf. the lower example in fig. 77, p. 172; see also the same author, The Danube in prehistory, pp. 40, 45, 1929.

[4] For an account of the Peruvian taclla, see Cook, O. F., Foot-plow agriculture in Peru, Ann. Rep. Smithsonian Inst. 1918, pp. 487-491, 1920. In view of the striking similarity of the taclla to certain western European implements, it may have been introduced into South America by the Spanish, as we know was the case with the traction-plow itself.

For information regarding the Irish laidh and its use I am much indebted to Dr. E. Cecil Curwen. The practice in vogue among the ancient Chinese is often mentioned in their classical books; for information concerning its modern survival I have to thank Dr. A. W. Hummel, of the Library of Congress, whose observations in the field confirm my own. The mode of using the Peruvian taclla is fully described in the paper by O. F. Cook cited above.

[5] Wundt, W. M., Elements of folk psychology (trans. by E. L. Schaub, undated), p. 291.

[6] Licent, Pére E., Collections Néolithiques du Musée Hoang ho Pai ho, vol. 1, p. 12, 1932.

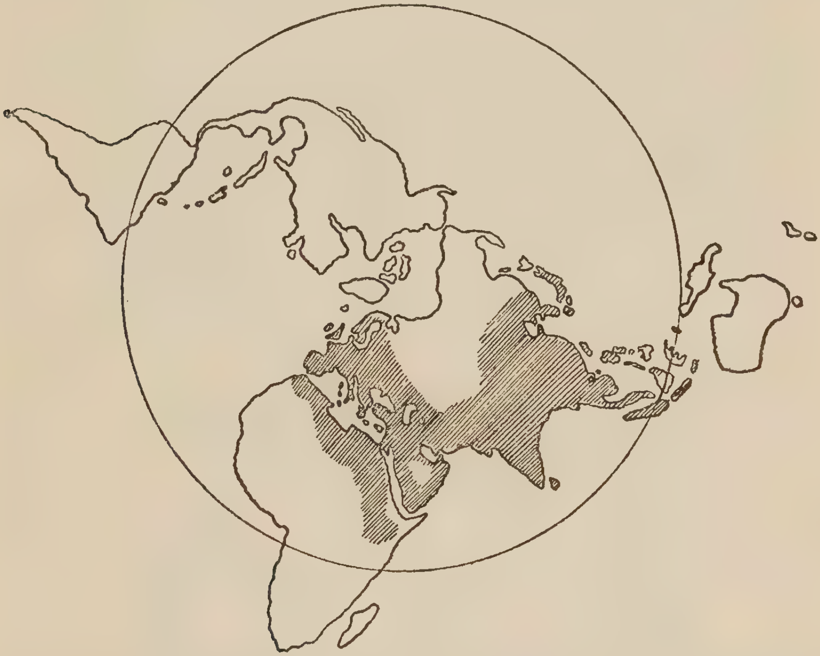

FIGURE 1.—Map showing approximately the distribution of the traction plow prior to the age of discovery (about A. D. 1500). The area indicated very closely coincides with that in which were found in antiquity many other important culture-elements, among them bronze, wheat, and the horse-drawn war-chariot.

The plow itself has often been regarded as a direct gift from the gods. The Egyptians ascribed its origin to Osiris, the great patron of agriculture, while the Vedic Indians believed that the Açvins had taught its use to mankind. In Greece its invention was variously imputed—to Zeus or Dionysos, to Pallas or Demeter. In China its origin came to be attributed both to Shên-nung, the "Divine Husbandman," and to a (mythical) grandson of Hou Chi, "Ruler of the Millet."

This intimate connection of the ox-drawn plow with religious ideology suggests the query whether it was not itself actually of priestly origin, and first employed in the production of sacred crops, destined for ceremonial uses. Examples of areas set aside for such a purpose are the Rharian (or Rarian) Plain near Eleusis, dedicated to Demeter, and the Sacred Field ceremonially tilled every spring by the Chinese emperors. Mesopotamian cylinder seals display the plowman garbed as a priest; or they show the plow in association with astral symbols or being offered to a seated god or goddess of agriculture (figs. 2–3). Again, a Cypriote clay model of a plowing scene from the Early Bronze Age, during the third millennium B. C., associates the plow with those cults of the Divine Mother and the Sacred Bull once so widely diffused over the Near East.[8] In many lands, too, the initial plowing of the year has been a solemn religious observance conducted in person by a priestly ruler; such, for example, was the case in China until less than a generation ago.

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[7] This question is well discussed by Wundt, op. cit., p. 290 seq.

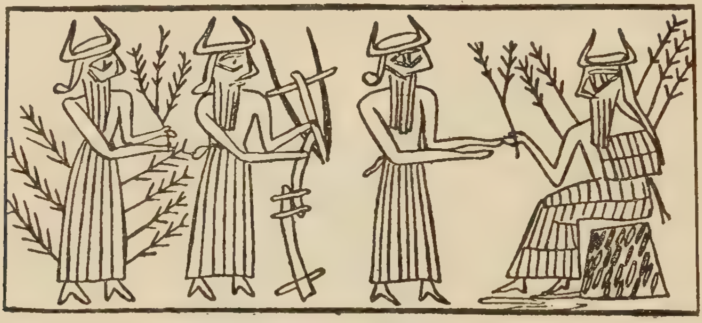

FIGURE 2.—Sumerian plow, about 2000 B. C. (After Ward, Seal cylinders, p. 133, No. 274.)

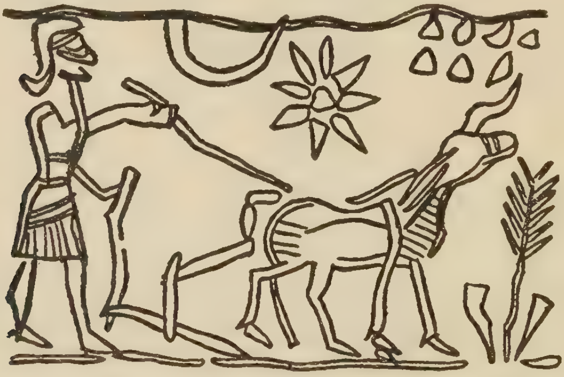

FIGURE 3.—Ancient Mesopotamian plowing scene. (After Ward, Seal cylinders, p. 132, No. 372.)

The earliest method of attaching cattle to the plow seems to have been by means of ropes made fast to their horns—the latter themselves magical symbols of great potency; both yoke and plow-beam appear to have been later developments. No doubt human and animal traction were employed in conjunction for a time. This continued to be the case in ceremonial traction in Egypt down to late dynastic times, and it is still the practice in certain backward regions.[9] Only through experience could men have discovered that, under proper guidance, oxen may be trained to draw the plow unaided.

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[8] Illustr. London News, December 10, 1932, p. 928 ff., and Man, No. 134, August 1933. For early contacts of Cyprus with the mainland of Anatolia and Syria, see Sir Arthur J. Evans, Scripta Minoa, p. 68, 1909.

We are as yet scarcely in a position to determine just when and where the traction plow first appeared. That its evolution should have occurred independently in more than one area is improbable in the extreme; for it involves the coordination of far too many culture elements. Moreover all the available historical evidence is opposed to such a view. Once the idea of using animals for drawing the plow had been grasped, however, its secular advantages assumed increasingly greater preponderance over its religious aspects, and its wide diffusion became inevitable. In many lands, in place of being associated with the introduction of any given form of plow, animal traction seems often to have been adapted to already existing agricultural implements of either the foot plow or the man-drawn type.

Recently it has been claimed that northern Europe—more specifically, the Nordic province—was the birthplace of the traction plow. This claim we shall discuss later. Credit for its invention has also been proposed for the valleys both of the Nile and of the Euphrates. Possibly its evolution actually began in Upper Mesopotamia or North Syria during late prehistoric times, when those regions enjoyed a greater rainfall than they do today.[10] The abundance of remains of human habitation in many parts of the Near East which are now arid proves that at no very distant date, geologically speaking, that region possessed a far higher degree of humidity than now.

The first irrefragable proof of the use of the traction plow anywhere is probably that found in an archaic Sumerian seal of about 3500 B. C., from the Royal Cemetery at Ur.[11] As the plow here shown is already as well developed in certain respects as its descendant of a thousand years later, we must postulate for it a long previous period of evolution. The actual beginnings of this process must go back at least as far as the fifth millennium B. C. or even before. The Uruk phase of prehistoric Babylonian civilization, commencing around 4000 B. C., perhaps as an intrusion from the northwest,[12] already employed animal traction for wheeled vehicles, and possibly in agriculture also, although this by no means necessarily follows. In ancient

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[9] For a recent instance, see Biddulph, Major J., Tribes of the Hindoo Koosh, p. 128, 1880.

[10] See Peake, Harold J., and Fleure, H. J., The steppe and the sown, p. 7, 1928.

[11] For this citation I am indebted to Dr. Leon Legrain, who tells me that the dating is still not quite certain. See Ur Excavations, vol. 2, The royal cemetery, p. 336, No. 12, and plate 192, No. 12, Joint Exped. British Mus. and Univ. Pennsylvania.

[12] Speiser, Dr. E. A., The ethnic background of the early civilizations of the Near East, Amer. Journ. Archaeol., 1933, p. 465.

Egypt, for example, the ox-drawn plow long preceded wheeled vehicles, while in China the exact reverse was the case.

The early Mesopotamian plow is most often shown with two handles or stilts, and, save apparently in ritual plowing,[13] the means of traction had progressed far beyond the primitive rope attached directly to the animals' horns. In some instances, even, we find depicted on the seals what seems to be a true neck-yoke, with bows or loops encircling the animals' throats.[14] There was no slade or sole, but merely a simple point. The plow-beam was of two pieces, joined together and sometimes displaying a double curve shaped like the sound-holes in a violin. Beams of this sort survive in the Near East to this day.[15]

The Babylonian plow seems to have undergone comparatively little change in form during the historical period. But by the latter half of the second millennium B. C., and perhaps much earlier, there was sometimes attached to it a "seeder"—an upright tube open at both ends, through which an attendant dropped the seed-corn as the plowing went on.[16] This apparatus appears also on Assyrian plows; representations occur on the walls of Sargon's palace at Khorsabad [17] and on monuments of Sennacherib and Esarhaddon.[18] Somewhat similar features shown on seals are interpreted as representing a man pushing down the plow point with a stick; but perhaps in reality what are intended are "seeders." [19] Little if any evidence exists for the very early use of metal shares in Mesopotamia; and indeed it is unlikely that such were ever regularly employed anywhere before iron came into general use.[20]

That cattle were the only animals attached to the plow by the ancient Babylonians seems clear. It has been asserted that on one very early carving a man is shown plowing with an antelope; however nothing in the way of a plow is depicted here, and what we have is in reality a hunting scene.[21]

We are far better informed in regard to the ancient Egyptian plow, of which we have so many representations, from the Third Dynasty onward.[22] It displays in general a more archaic aspect than the Mesopotamian plow; but like the latter it usually has two handles, at first very short. In the earliest reliefs the Egyptian plow is often attached to the draft animals simply by a rope tied to their horns; and even in later times, at any rate in ritual traction, a yoke is frequently absent (fig. 4). When it does occur under the Old and Middle Kingdoms, it is of the most primitive description—merely a bar of wood lashed crosswise to the animals' horns. Although hornless cattle were known to the ancient Egyptians they seem never to have been used in plowing.[23] Where in place of a rope a plow-beam is shown, it is usually short and always straight and displays none of the elaboration of Babylonian examples.

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[13] See fig. 5, representing a late Cassite plowing scene, obviously ritual in character; the difference in the position of the animals' heads emphasizes the absence of a yoke.

[14] Ward, W. B., The seal cylinders of Western Asia, p. 132, Nos. 369, 371, 1910.

[15] For a modern instance see Festschrift: Publication d'hommage offerte au P. W. Schmidt, 1928; Leser, Paul, Westösliche Landwirtschaft, p. 434, fig. 32.

[16] See fig. 5, p. 528.

[17] Leser, Paul, Entstehung und Verbreitung des Pfluges, p. 247 and note 53, 1931. Plowshares were among the iron objects found in Sargon's palace. Some are now in the Louvre.

[18] For an example from a monument of Esarhaddon, cf. Pinches, O. T., The old testament in the light of the historical records of Assyria and Babylonia, pl. 13, opp. p. 208, 1902.

[19] Ward, op. cit., pp. 132, 133.

[20] For plow irons at Gerar about the twelfth century B. C., cf. Wainwright, G. A., The coming of iron, Antiquity, 1936, p. 19.

[21] For the scene thus wrongly explained, see Hilprecht, H. V., The Babylonian Expedition of the University of Pennsylvania, vol. 1, pl. 16, p. 88, 1893; also Ward, op. cit., p. 30, no. 55. Dr. Legrain has confirmed my own suspicions in regard to the true purport of this carving.

The use of a cross-tie of twisted and doubled thongs or cords, binding the beam to the lower part of the plow, near the point, arose quite early, but only became general toward the beginning of the Twelfth Dynasty; later still it was replaced by a cross-brace, apparently of wood. The Egyptians seem to have armed their plows with flint during most of the Dynastic Period;[24] although there is some evidence that they were beginning to employ metal shares before its close.[25]

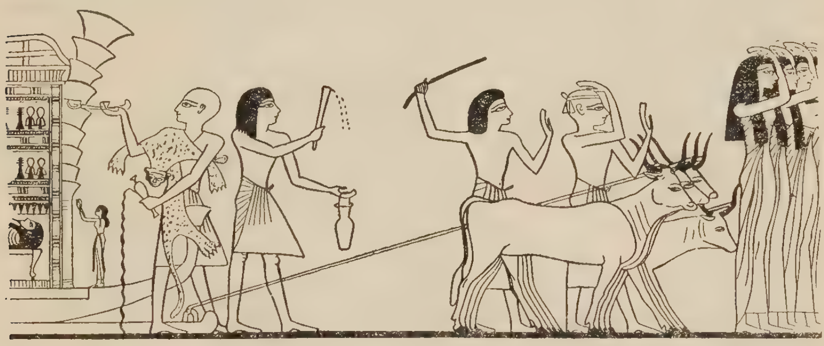

FIGURE 4.—Late Dynastic Egyptian ritual traction illustrating method of attachment without either yoke or pole. (After Wilkinson, Ancient Egyptians, vol. 3, pl. op. p. 449, 1878.)

Save in minor details, the Egyptian plow underwent little evolution during Old and Middle Kingdom times. It was only after the Hyksos conquest—when, incidentally, wheeled vehicles first appeared in Egypt—that changes in the plow became more marked. It then grew progressively heavier and its stilts longer, while true neck-yokes, perhaps introduced from Asia, began to replace the archaic bars of wood tied athwart the animals' horns.[26] In some of the later Dynastic

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[22] On Third Dynasty plows, see Petrie, W. M. Flinders, The tomb of Nefermat, Medum, 1892.

[23] Schaefer, Heinrich, Priestergräber * * * vom Totentempel des Ne-user-rê, p. 17, 1908.

[24] Cf. Hartmann, Fernande, L'Agriculture dans l'ancienne Égypte, p. 79, fig. 10, 1923; also De Morgan, Jacques, Prehistoric man, p. 172, 1924.

[25] See Schaefer, op cit., p. 168.

[26] Cf. Antiquity, vol. 9, p. 456, 1934, referring to the Papyrus of Kumara. The oxcarts of the Asiatic foes of Rameses III have neck-yokes.

Egyptian plows there appears to be a tendency to develop a slade or sole—a feature apparently already known in the Aegean area; possibly its appearance in Egypt was connected in some way with those raids by the "Sea Peoples" then going on. Something which has very much the look of a coulter (not necessarily of metal) also appears in a few representations of plows on New Kingdom monuments, and at least one surviving example has actually been reported.[27]

Instances of the use of human instead of animal traction in plowing are rare. An Eighteenth Dynasty relief (fig. 6) shows a plow of the usual type drawn by four youths and guided by an older man who is closely followed by a sower.[28] The form of the plow here is wrongly reproduced by Lepsius [29] and by those who have copied him.

We know little as yet regarding the first appearance of the traction-plow in Asia Minor. As we have seen, the eastern portion of that area was perhaps not far removed from the original center of diffusion.

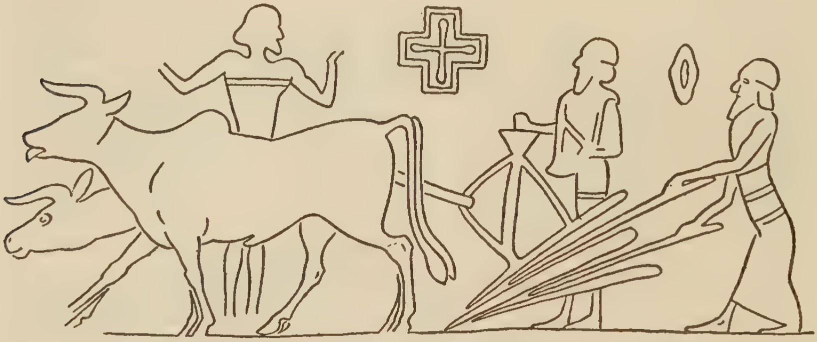

FIGURE 5.—Plowing scene on late Cassite seal-impression. (From University of Pennsylvania Museum Journal, vol. 1, p. 4, 1910.)

A high degree of civilization existed in the region west of the Taurus by the third millennium before our era,[30] when the plow was already known in Egypt and Cyprus. That it was used in Asia Minor as early as it was in the latter of these two regions at least, we may regard as certain. The peninsula became indeed in the course of time a secondary area of diffusion. For more detailed information we shall have to await further archeological research.

It was perhaps from Asia Minor that the traction plow reached Crete. For the form used there during Minoan times, as it is depicted in the hieroglyphic script, shows no resemblance to those ordinarily used either in Mesopotamia or in Egypt. Unlike these, it has but a single handle, with a transverse hand-grip, and a well developed slade in one piece with the beam. Both these characters the ancient Cretan plow shares with examples found in peat bogs in northern Europe; and it seems also to have been nearly related to the preclassical Greek plow as well as to types found in the eastern Mediterranean area today.[31] It displays a distinctly more developed shape than do the plows shown in the Ligurian and Swedish petroglyphs which we shall discuss later.

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[27] Cf. Burkitt, M. C., Our early ancestors, p. 54, note 1, 1926. On the other hand, Dr. E. A. Speiser informs me that the mention of "coulters" in I Sam. 12:20 and 21, is an anachronism due to a mistranslation.

[28] Tylor, J. J., and Griffith, F. Ll., The Tomb of Paheri at El Kab, vol. 1, p. 13 and pl. 3, Egypt Explor. Fund, Eleventh Mem., London, 1894.

[29] Lepsius, Richard, Denkmäler aus Aegyptien und Aethiopien, vol. 3, pl. 10–a.

[30] Smith, Sidney, History of Assyria to 1000 B. C., pp. 164 ff., 1928.

There appears to be no conclusive evidence for the use of the ox-drawn plow in Europe during the Neolithic period,[32] although some form of foot plow was pretty surely known and perhaps human traction was also employed. However, Mesopotamia was in contact from very early times with the steppe lands north of the mountain zone,[33] and it was perhaps in this way that the idea of employing animal traction in agriculture reached that black earth region destined one day to become the granary of Athens. From southern Russia—or perhaps from Asia Minor, though the latter seems on the whole the less likely source—the use of the plow spread to the Danube Valley. It may possibly have appeared there during the latter half of the third millennium before our era; for among remains of the culture known as Danubian II, which seems to have arisen about that time, there have been found large stone implements interpreted as plow-

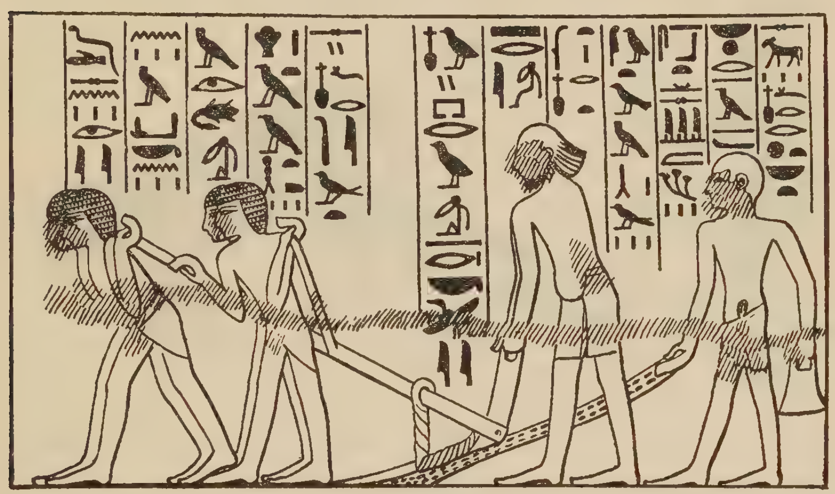

FIGURE 6.—Egyptian eighteenth dynasty example of human traction in plowing. (From Tylor and Griffith, Paheri, vol. 1, pl. 3.)

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[31] For hieroglyphic representations of the ancient Cretan plow, cf. Evans, Sir Arthur J., Scripta Minoa, pp. 190 ff., and fig. 102 (table 13), No. 27, 1909.

[32] Childe, V. Gordon, The Bronze Age, p. 49, 1930; also, Leser, Paul, Entstehung und Verbreitung des Pfluges, p. 550.

[33] Childe, The Aryans, pp. 185 ff., 1926.

shares.[34] The latter may, it is true, have belonged to man-drawn implements; but in any case it seems fairly certain that the Danube Basin knew the true traction plow by the beginning of the second millennium B. C.

It was perhaps both through the Balkans and either directly from Asia Minor or else through Crete that the use of the ox-drawn plow spread to Greece. For Hesiod speaks of two types as in use concurrently in his day.[35] Of these, one, very simple in construction, may possibly have been derived from Central Europe; while the other, considerably more developed, points rather to contacts with the Aegean area or possibly with regions even farther to the east. Both forms have single handles and also slades, but apparently not metal shares.

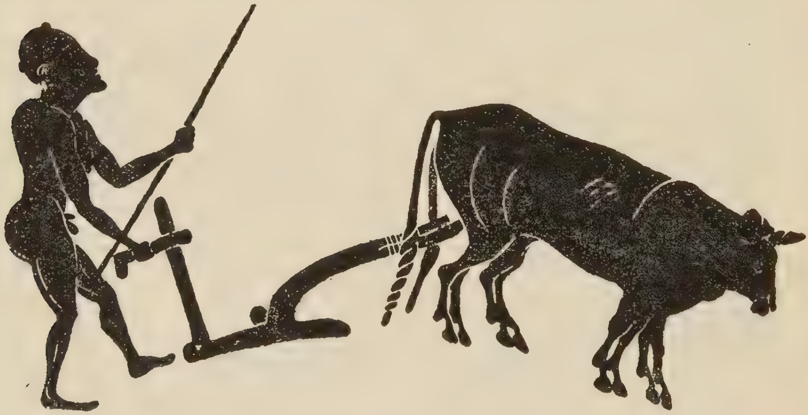

FIGURE 7.—Ancient Greek plow. (From a vase-painting by Nikosthenes.)

Our earliest knowledge of the ancient Greek plow we owe almost entirely to Homer and Hesiod, and, a little later, to the vase painters (fig. 7).

In Italy there seems to have been little in the way of true agriculture during Neolithic times.[36] Not until the Bronze Age is the traction-plow found there. Perhaps it was introduced by the Terremare people—Dr. Randall MacIver's "Proto-Italici"—invaders from the northeast who appeared in Upper Italy somewhere around 1700 B. C., bringing with them a highly developed agriculture.[37] Our earliest concrete evidence for the plow in the peninsula is probably that found in certain rock drawings in the Ligurian Alps.[38] These are generally believed to date from the second millennium before our era—during the period, that is to say, when the influence of the Terremaricoli was making itself felt in northern Italy. It seems unlikely that these petroglyphs can have been the handiwork of the native Ligures, whom Posidonius describes in the first century B. C. as "wild huntsmen, almost ignorant of agriculture."

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[34] Regarding the intrusive elements, apparently deriving from southern Russia, which appear in Danubian II, cf. Childe, Dawn of European civilization, p. 177, 1925; on p. 179 of the same work, Danubian II is dated c. 2500-2200 B. C.

[35] Works and days, pp. 427-436.

[36] MacIver, Randall, Italy before the Romans, p. 41, 1928.

[37] MacIver, Randall, op. cit., pp. 35, 36.

[38] For an account of these, see Burkitt, M. C., Rock carvings in the Italian Alps, Antiquity, vol. 3, pp. 155-164, 1929.

The plow shown here was composed of two pieces, a combined handle and point and a beam. So far as our evidence goes, this was the only form in use in Italy for several centuries.[39] It was apparently not until the earlier half of the first millennium B. C. that there was introduced an improved form, having a slade, and comparable in other respects also to the more developed type mentioned by Hesiod.[40] Its arrival in the peninsula was pretty surely connected with the movements which led to the settlement of the Etruscans northwest of the Tiber and of the Greeks in Magna Graecia.

During the Roman period agricultural implements of all kinds underwent a marked development. Among the new devices then adopted seem to have been mould-boards, a wheeled forecarriage, and definitely the coulter.[41] These improvements were perhaps the work not alone of the peoples of Italy but also of some of those dwelling beyond the Alps. In any case, they were diffused over a large part of western and central Europe, where their evidences are visible throughout the Middle Ages and even down to our own times (*cf.* pl. 1).

That the peoples of the Iberian Peninsula had the traction plow before the Roman occupation is certain; but as to the date of its first appearance there we are quite in the dark. It may have been introduced there during the Celtic invasions,[42] or, even earlier, from northern Italy, between which and Spain we know that there were contacts. The Celtiberians had a two-piece plow without a slade and in general resembling that shown in the Ligurian petroglyphs;[43] while some of the more archaic Spanish and Portuguese plows used down to recent times recall forms found in central and even eastern Europe. The Greeks and Carthaginians can of course scarcely have failed to bring with them improved eastern Mediterranean types.

Regarding the presence of the plow in North Africa (west of Egypt) before the former half of the first millennium B. C., our knowledge is slight. In early historical times the Libyans seem on the whole to have been pastoral;[44] yet they grew cereals in the time of Merneptah, late in the thirteenth century B. C.[45] Among the modern Berbers there has been noted an agricultural complex, apparently of great age, including along with many magical practices the use of the ox-drawn plow, regarded as sacred.[46] Agriculture in North Africa must have received a great stimulus from the planting of the Phoenician and Greek colonies along the littoral. The Carthaginians in particular developed it to a very high pitch, as we are told by more than one ancient writer; Columella, for example, in the first century A. D., even calls Mago "the father of husbandry."[47]

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[39] This form seems to have been the forerunner of the Roman aratrum simplex, comparable to Hesiod's αὐτόγυον ἄροτρον.

[40] The πηκτὸν ἄροτρον.

[41] See Huntingford, G. W. B., Ancient agriculture, Antiquity, vol. 6, p. 328, 1932.

[42] For a brief discussion of these as they relate to Spain, see Kraft, Georg, The origin of the Kelts, Antiquity, vol. 3, p. 33 passim, 1929.

[43] For a representation of a Celtiberian plow on a coin, see Daremberg-Saglio, Dict. des Antiq., vol. 1, p. 354, fig. 434.

[44] Cambr. Anc. Hist., vol. 1, p. 36.

[45] Bates, Oric. Eastern Libyans, p. 98, 1914.

It was most probably during the Late Bronze Age that the ox-drawn plow reached western Europe—say somewhere around the beginning of the first millennium B. C. During the same period or very early in the Iron Age it seems to have appeared in Britain;[48] although some have doubted its arrival there before the Roman conquest in the first century A. D.[49] That the earliest British plow resembled those shown in the Ligurian petroglyphs seems likely, while its ultimate derivation from the Danube basin hardly admits of a doubt. After the Saxon conquest the older and lighter Celtic plow was in a measure displaced by a heavier one, drawn by as many as four yoke of oxen—a type perhaps devised in South Germany during the early centuries of our era.[50]

The same form of plow as that first found in northern Italy and in all likelihood in western Europe also reached the Baltic area. An article has recently appeared undertaking to prove, through a resort to pollen analysis, that a traction plow found in a peat-bog at Walle, in East Friesland, belongs to Neolithic times—according to this author, as long ago as 3500 B. C.[51] This would carry us back as far as the first recorded appearance of the plow in ancient Sumer, and something like a round millennium before the earliest probable date of its arrival in Central Europe. The writer of the above paper further points out that the Walle plow is similar to those shown on the Certosa situla and on certain Greek vases—the implication, of course, being that the type persisted practically unchanged for some 3,000 years, during which it diffused itself slowly southward from the Baltic to the Mediterranean.

Any such dating as that claimed for the Walle plow is, on *a priori* grounds alone, most improbable—unless we are prepared to admit for the prehistoric Germans a wholly independent focus of culture development of their own, somewhere in the Baltic area. Moreover, valuable as is pollen analysis for some purposes, any effort to establish by that method alone the age of intrusive objects (particularly heavy ones) found in peat-bogs is, to say the least, extremely hazardous. Finally, the Walle plow seems crudely constructed rather than truly primitive in form—which is by no means the same thing. We shall need much more convincing evidence than any as yet adduced before we can accept the north of Europe, whether in the fourth millennium B. C. or at any other time, as the birthplace of the traction plow.

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[46] Coons, C. S., Tribes of the Rif, Harvard African Studies, vol. 9, pp. 49 ff., 1931.

[47] De re rustica, vol. 1, No. 1, p. 13.

[48] Curwen, E. Cecil, Prehistoric agriculture in Britain, Antiquity, vol. 1, p. 287, 1927.

[49] Peake, Harold J., Early steps in human progress, p. 122.

[50] Cf. Curwen, loc. cit., Antiquity, vol. 1, pp. 280 ff., 1927.

[51] Jacob-Friesen, Dr., Die älteste Pflug der Welt, Natur und Volk, vol. 64, pp. 83–91, 1934. See also Jirlow, Ragner, Plogkroken från Svarvarbo och några förhistoriske plogar (with summary in German), Upplands Fornminnesförenings Tidskrift, vol. 45, No. 1, pp. 1–19. For calling my attention to the latter paper, I am indebted to the editor of Antiquity.

That the latter was known, however, in the Baltic area during the Bronze Age or, at latest, early in that of Iron is certain. Depicted in the well-known rock-drawings of Bohuslän, in southern Sweden, are plows of two types. One (pl.2,fig.1),of two pieces only,is closely similar to the form shown in the Ligurian petroglyphs. The other is like it save for the addition of a third member in the shape of a cross-brace identical in function to that found in the later dynastic Egyptian plows.

One writer calls these Swedish petroglyphs "incontestably of the Early Bronze Age."[52] Others regard them as belonging to the Middle Bronze Age. Sophus Müller says merely that they are "centuries later" than their Ligurian analogues.[53] The same scholar, while discussing a plow found in a bog at Døstrop, in Jutland,[54] strikingly like the simpler of the two types seen at Bohuslän, states that it is either of the Late Bronze Age or early in that of Iron.[55] In any case it seems clear that the ox-drawn plow was known in Sweden by the middle of the first millennium B. C. or possibly a few centuries earlier.

The Swedish "plow-crook," long drawn by hand and only in comparatively recent times by mares or cows, closely resembled the two-piece plow at Bohuslän. Like the latter, it consisted of only two members—a combined handle and point and a beam or pole.[56] In Sweden as elsewhere, what seems to have been the earlier method of traction, by human power, long survived side by side with that which depended upon the use of animals.

The unmistakable resemblance between the plows shown in the Ligurian and in the Swedish petroglyphs is best explained on the assumption of derivation from a common source—almost certainly the valley of the Danube.

Whether the Indus civilization had the ox-drawn plow is as yet uncertain.[57] Northwestern India was, however, in active commercial communication with Babylonia at a time when the latter had already long known the plow; hence its contemporary use in the valley of the Indus seems at least possible. At all events it was common there in Vedic times;[58] and it appears to have spread over much if not all of northern India before the middle of the first millennium B. C.

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[52] Jacob-Friesen, loc. cit., Natur und Volk, vol. 64, p. 84, 1934.

[53] Müller, Sophus, Urgeschichte Europas, p. 147.

[54] The Døstrop plow is shown in Mems. Soc. Royale des Antiquaires du Nord, 1902, p. 21, fig. 1, in connection with the article by Sophus Müller cited in footnote 2.

[55] The Scandinavian Iron Age appears to have begun not very far from 600 B. C.

[56] Sayce, R. U., Primitive arts and crafts, p. 115, 1933.

[57] Marshall, Sir John, Mohenjo-Daro and the Indus civilization, vol. 1, p. 27; vol. 2, p. 456 and note 1; 1931.

The ancient Indian plow (fig. 10) reached Burma and southern India in time, and it was carried during the earlier centuries of our era to portions of the Indochinese peninsula and to certain of the East Indian islands, notably to Java. The form still used in Bali, with its straight beam and its lack even of a cross-brace, wears an especially archaic look; while the Siamese rice-plow betrays strong Indian affinities.

In Central Asia not enough archeological work has been done as yet to provide us with any clue as to the date of the first appearance of the traction plow in that region. Forms found there today, however, resemble those used in the Near East—a fact which betokens contacts of some sort. These have, of course, been constant since the period of Muhammadan expansion north and northeast of the Mountain Zone. That they were going on far earlier is no less certain.

Common wheat (*Triticum vulgare*) and barley (*Hordeum distichum*), regarded by most authorities as of southern or southwestern Asiatic origin, have been reported from a site in Russian Turkestan probably of the third millennium B. C.[59] The undivided Indo-Iranians, perhaps once seated in the same general region, knew some form of plow.[60] Coming down to Assyrian times, the representation of a two-humped or "Bactrian" camel on the Black Obelisk of Shalmaneser (ninth century B. C.) pretty clearly indicates the existence of relations of some sort with the lands north of the Zagros and the Hindu Kush. The *Arimaspeia* of Aristeas of Proconnesos betrays an intimate knowledge of Central Asia.[61] During the latter half of the sixth century B. C., both Cyrus and Darius pushed their conquests far to the northeast. Quite recently there have been found in Chinese Turkestan Greek coins of the third century B. C., from the kingdom of the Bosphorus.[62] Thus all in all it seems evident that so far as opportunities went, the traction plow might have reached Central Asiatic regions at almost any time during the first two millennia and more before our era.

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[58] Cambr. Hist. India, vol. 1, p. 99. For additional information on this matter I am indebted to Dr. Franklin Edgerton, of Yale University.

[59] Pumpelly, Raphael, Explorations in Turkestan, vol. 2, p. 472, 1908. Dr. Hubert Schmidt's dating (idem, vol. 1, p. 486) of the earlier settlements at Anau as being of the third millenium B. C. appears to have received general acceptance.

[60] Peake and Fleure, The horse and the sword, p. 138, 1933. That the Indo-Europeans as a whole had the plow prior to their dispersion seems less certain.

[61] For a discussion of this question, see Hudson, G. F., Europe and China, 1931.

[62] Diehl, Dr. Erich, Bosporanische Münzen aus der Dschungarei, Blätter für Münzfreunde, 1923, pp. 441–449.

This possibility is further strengthened by the fact that the varieties of wheat grown in Central Asia and even in China are identical with those of the Near East.[63] Wheat (*T. vulgare* and perhaps also *T. compactum*) had reached China by the middle of the second millennium B. C., as is shown by nearly contemporary inscriptions. The same seems also to have been true of barley (probably *H. distichum*). These cereals were not, however, accompanied by the traction plow, although the Chinese of that day employed both horses and bullocks to draw wheeled vehicles. The usual agricultural implements used by the peasantry of the Chinese Bronze Age [64] were various forms of the foot-plow, used by men working in pairs. So typical was this practice, indeed, that the ideograph meaning "a pair" (of any sort) was formed of two *lei*—implements of the foot-plow class—depicted side by side. Further, the pictograph representing a single *lei* became the determinative or "signific" of a large class of characters having to do with agriculture. It seems likely, in the light both of numerous existing survivals and of certain statements in the ancient Chinese texts, that human traction also was once widely employed in Eastern Asia.

There is no mention of the ox-drawn plow in China during the earlier historical period. This might be taken merely for negative evidence were it not that we find the definite statement that it was introduced "about the middle of the Epoch of the Warring States" (403–255 B. C.)—that is to say, sometime in the latter half of the fourth century before our era.[65]

This dating is significant. For it was precisely then that the feudal state of Ch'in [66]—corresponding roughly to the present northwestern province of Shensi—annexed the eastern termini of both the two great land-routes linking China with the Occident.[67] Of these, one was, of course, that traversing Central Asia; while the other connected western China, by way of Burma, with the valley of the Ganges. Now Ch'in was noted not only for her devotion to war but also for her encouragement of agriculture and her receptivity toward new ideas. She, more than any other Chinese state of that day, would have been likely to welcome and adopt the traction plow.

By which of the two routes just mentioned knowledge of the plow made its way to China, we cannot say. Possibly it may have spread to the basin of the Huang Ho (the Yellow River) through Central Asia; and to that of the Yangtze from Farther India, along the same path as that taken in prehistoric times by rice, the domestic fowl, and other culture-elements.[68] In any case, once it had appeared, it seems to have spread within a century or two over most of northern and central China proper.

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[63] Vavilov, N. I., Geographische Genzentren unserer Kulturpflanzen, Zeitschr. für induktive Abstammungs- und Vererbungslehre, suppl. I, p. 352 and map on p. 353, Leipzig, 1928.

For a discussion of Vavilov's views, see Watkins, A. E., The origin of cultivated plants, Antiquity, vol. 7, pp. 73–80, 1933.

[64] The Chinese Bronze Age lasted from the former half of the second millenium until the latter part of the first before our era.

[65] For this citation I am indebted to Dr. A. W. Hummel.

[66] Ch'in was the state destined about a century later to establish the first centralized and bureaucratic Chinese empire; from its name comes ours of "China."

[67] The sea-route to the Far East only came into use around or perhaps very shortly before our era, when Western ships began to appear in southern Chinese waters.

It is noteworthy that when the need arose for a written symbol to denote the new implement, the determinative chosen was not that in regular use with ideographs having to do with agriculture (see p. 545) but the character for "ox"; as though in the minds of the Chinese scribes the significant thing about the plow was not so much its use in tillage as its association with animal traction.

The Far Eastern plow of today is frequently (although by no means invariably) drawn by one or sometimes two animals harnessed with rope traces to a swingletree pivoting on the end of a short and usually much curved plow-beam (pls. 4 and 5). Whether this method of attachment is really ancient in China is uncertain; but we know from the evidence of old paintings that it was in use at least as far back as the twelfth century A. D.[69]

North of China, in Mongolia, the sedentary "peasant" type of culture which occupied that area during Neolithic times had given place, apparently by the middle of the first millennium B. C., to a pastoral nomadism not unlike that found there today. In this, the plow could naturally play little part. In other directions—east, west, and south—the spread of the traction plow from China as a secondary center of diffusion went on apace. Here the Chinese accounts are of particular value for the light that they throw upon the workings of a process which in the lands of the Occident had gone on largely unrecorded.

Thus it was from China that the plow reached eastern Tibet—according to a late source, in the early centuries of the Christian Era; in the central and western portions of that country, as we might expect, Indian contacts are more apparent.

From the Yangtze Valley the plow traveled to what are now southern China and French Indochina, perhaps just before the commencement of our era. From northern China, around the same period, the plow reached southern Manchuria and Korea. Either from the latter country or directly from China it was carried, about the fifth or sixth century A. D., to the Japanese islands. But there it never acquired first-rate importance, the peasantry placing dependence rather upon hoes, mattocks, and implements of the foot-plow and man-drawn classes.

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[68] The importance of this "back-door" to China has never received the recognition which it deserves; yet through it have come many important elements of the Chinese civilization from prehistoric times down to the present day.

[69] Dr. A. W. Hummel has very kindly brought to my attention Chinese paintings of that period in the Library of Congress which illustrate the point involved.

From China, again, the traction plow traveled to the East Indian Archipelago, occupation of which it shared with the type from India. Generally speaking the line of demarcation between the two fields of cultural influence extends, though with many interpenetrations, from east-central Tibet southward through the Indochinese peninsula, thence swinging off in a southeasterly direction into Indonesia. Formosa, the Philippines, and North Borneo remain on the Chinese side, while Sumatra, Java, and their nearer neighbors fall within the Indian sphere. It seems to have been only in this quarter of the globe that the traction plow in its earlier career penetrated, albeit very slightly, south of the Equator.

Let us now summarize briefly the results of our inquiry. These seem to make it fairly clear that the traction plow appears at progressively later dates the farther we travel, in whatever direction, from the region where we find the earliest indications of its use—that is to say, in the ancient Near East. Moreover its extension, so far as we have been able to trace it through written records, has invariably been due to diffusion—to culture borrowing, never to repeated independent invention. There is every reason to believe that the same holds true for prehistoric times, also. These facts go a long way toward accounting for that essential unity underlying the agricultural systems upon which have been based the great civilizations of the Old World.[70]

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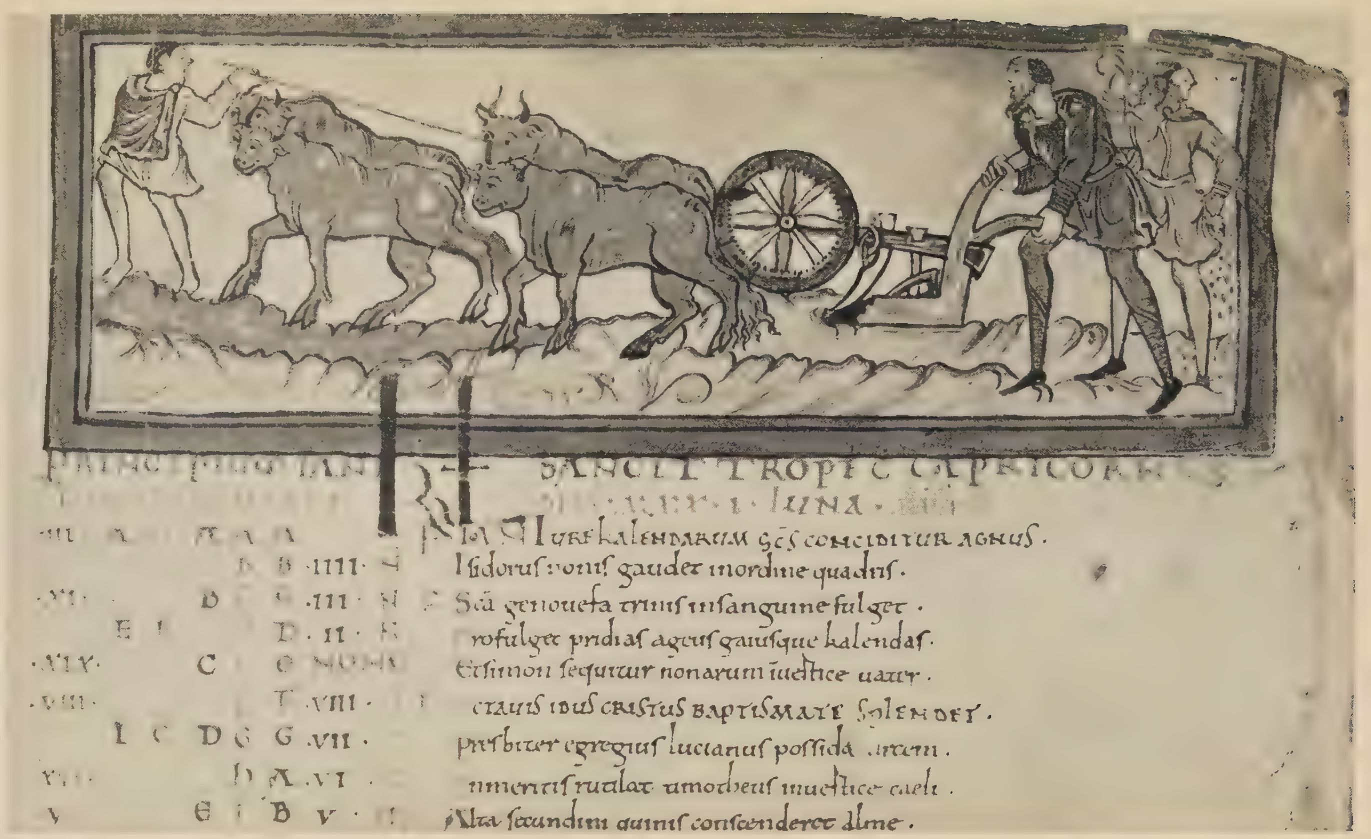
[70] On this unity, see Leser, Paul, Entstehung und Verbreitung des Pfluges, p. 545, 1931; also his paper in Festschrift Schmidt cited in footnote 15.



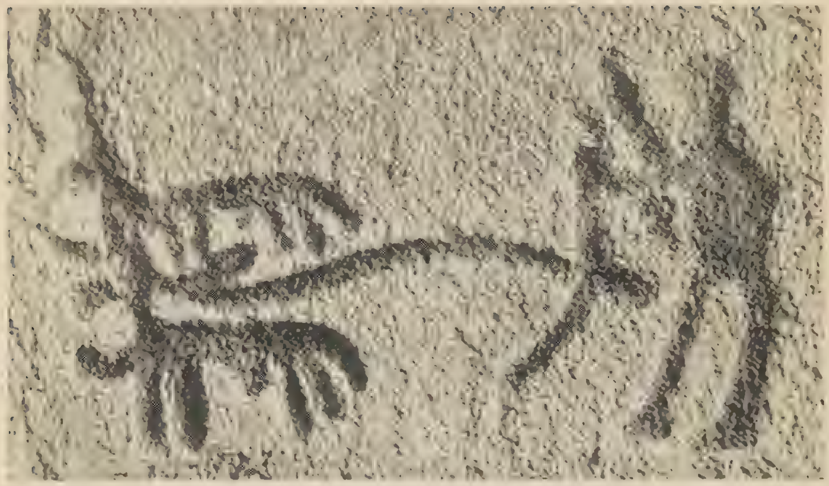
SANCTI TROPIC CAPRICORN

LUNA

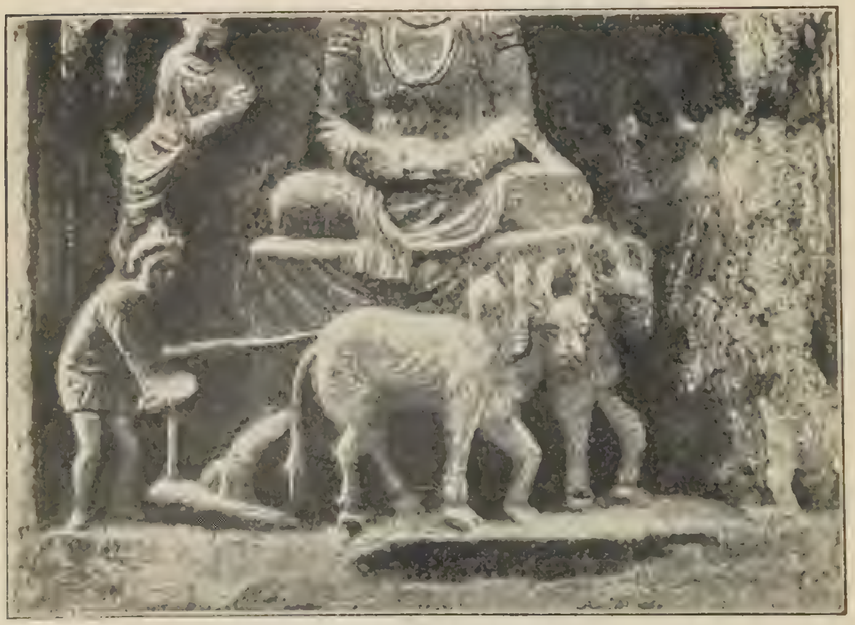
Iure kalendarum gēs concidıtur agnus.
Iſidoruſ nonis gaudet inordine quadriſ.
Sc̄a genoueſa trinis inſanguine fulget.
rofulget pridiaſ ageuſ gaiuſque kalendaſ.
Etſimon ſequitur nonarum iueſtice uatur.
ctauis idus cristus baptismate ſplendet.
preſbiter egregiuſ lucianuſ poſſida arcem.
nmentiſ rutilat timotheuſ inuethce caeli.
Alta ſecundum quiniſ conſcenderet alme.

Copyright, British Museum.

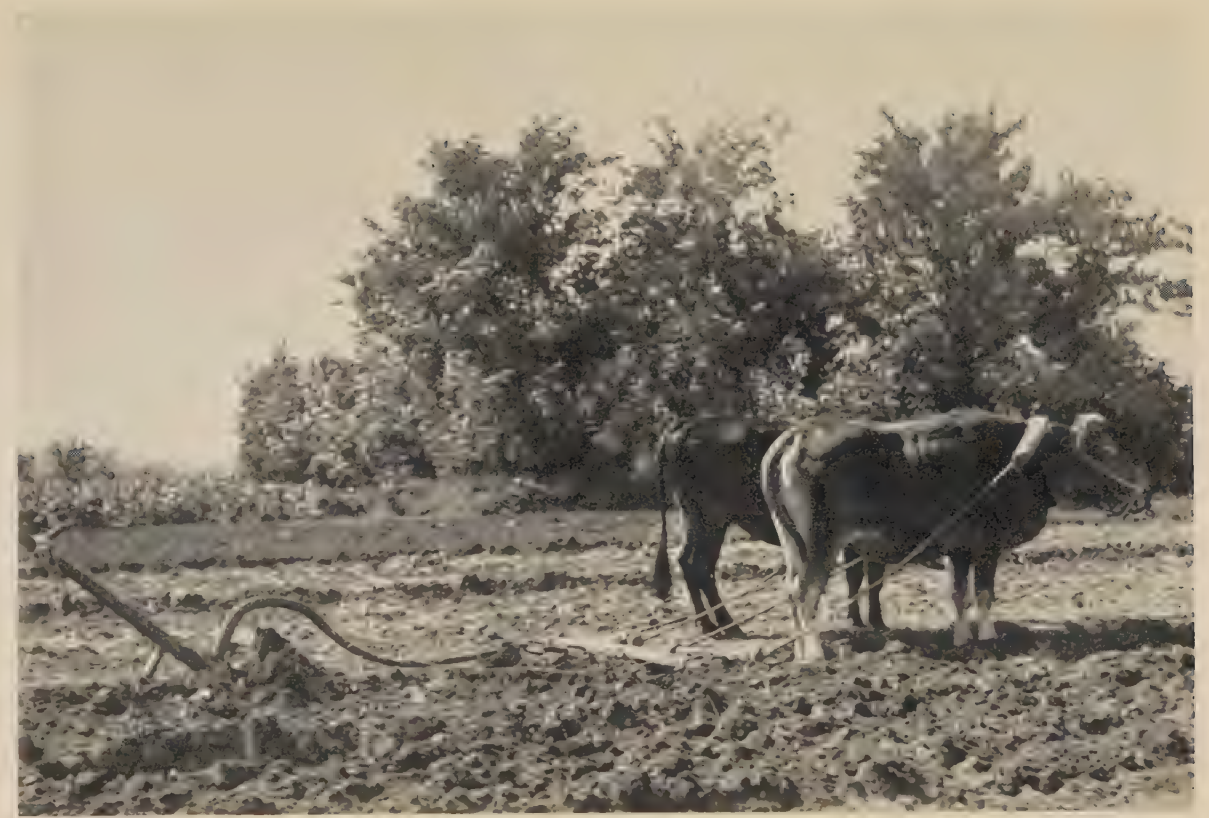
FROM COTTONIAN MS. TIB. V. (PART 1), FOL. 3. (ELEVENTH CENTURY.)



1. SIMPLER OF THE TWO TYPES OF PLOWS SHOWN AT BOHUSLÄN.
(After Sophus Müller.)

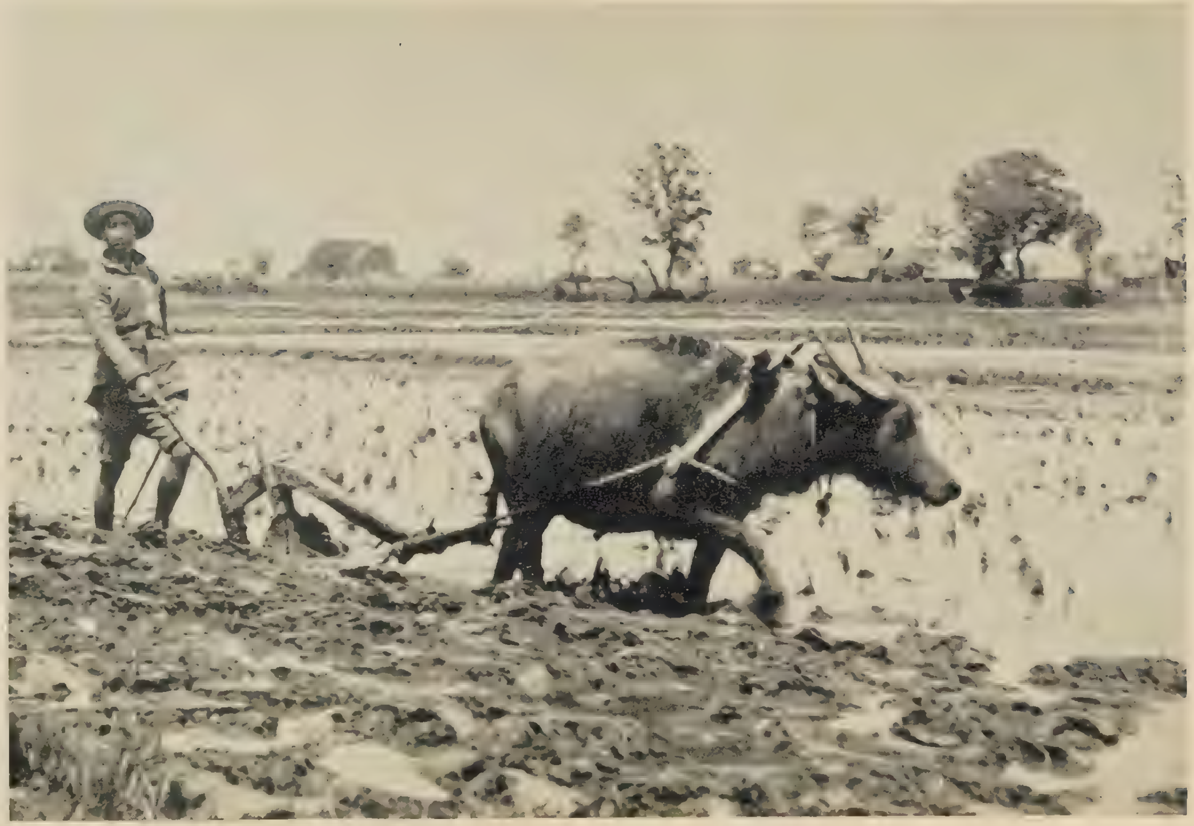


2. INDIAN PLOW OF THE GANDHARA PERIOD.
(After A. Foucher, L'Art gréco-bouddhique de Gandhara, vol. 1, p. 342, fig. 175.)



White Brothers

Northern Chinese Plow With Curved Iron Beam and Swingletree.



White Brothers.

PLOW DRAWN BY A SINGLE ANIMAL COMMON IN CENTRAL AND SOUTHERN CHINA AND IN SOUTHEASTERN ASIA GENERALLY.

HISTORICAL NOTES ON THE COTTON GIN

By F. L. Lewton
Curator, Division of Textiles, United States National Museum

[With 4 plates]

I. INTRODUCTION

The story of the invention of the cotton gin in 1793 by the young Yale University graduate, Eli Whitney, has been told many times, and in the main these accounts agree, though differing widely on minor details. As is the case with almost every important invention, claims have been made that others than the real inventor should be given credit for the discovery of the original idea, for the first practical machine, or for really "putting it over" and making the invention a success. The history of the invention of the cotton gin, with all it has meant to the South, is no exception to the usual story of all our successful inventions.

Local traditions concerning the details of an event many years after it happened are often impossible either to verify or to disprove, and some of the stories relating to the invention and introduction of the cotton gin are in the same class with the universally told story of George Washington and the cherry tree.

It is not the purpose to sketch here the life of Eli Whitney or to retell the events leading to and following his invention of the cotton gin bearing his name. Olmsted, Scarborough, Hammond, Bates, Tompkins,[1] and others have told this story; their accounts, while agreeing in the main, exhibit many discrepancies and contradictions and sometimes strongly reflect sectional bias. A recent study, however, of many of Whitney's letters, of numerous early accounts of his activities in the South, and of several models of the gin that are still in existence, has thrown some new light on the answers to a number of questions that have been asked in regard to the origin and operation of the Whitney cotton gin.

Since most of the publications examined are out of print at this date and many of the parts of the periodicals referred to are not even to be found in most of the larger libraries, it has seemed advisable in collecting these historical scraps to quote directly from the publications instead of merely giving references to the literature consulted.

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[1] See p. 563 for list of general works cited.

II. ELI WHITNEY'S PATENT

Owing to the complete destruction of the United States Patent Office by fire on December 15, 1836, and the consequent loss of all models and specifications, the question has been raised as to what were the original specifications of Whitney's patent and what kind of a model did he file with his application for the patent.

Whitney filed his application with the Secretary of State, Thomas Jefferson, on June 20, 1793. He had left Georgia immediately after signing his partnership agreement with Phineas Miller, on May 27, 1793, for the purpose of constructing a model for the Patent Office, as the law required. He states that he went to New Haven, Conn., for that purpose, as he could not obtain the necessary materials in Georgia. He writes from New Haven to his father in Westboro, Mass., on September 11, 1793:

> I returned to the Northward for the purpose of having a machine made on a large scale and obtaining a patent for the invention. I went to Philadelphia soon after I arrived, made myself acquainted with the steps necessary to obtain a Patent, took several of the steps, and the Secretary of State, Mr. Jefferson, agreed to send the Patent to me as soon as it could be made out. So I apprehended no difficulty in obtaining the Patent * * *. As soon as I have got a Patent in America I shall go with the machine I am now making, to Georgia, where I shall stay a few weeks to see it work * * *.[2]

The prevalence of yellow fever in Philadelphia delayed finishing his business in regard to the patent, but on October 19, 1793, he sent a drawing of his cotton gin to Mr. Jefferson. As a matter of safety, to prevent being anticipated by anyone else in the matter of the patent, he took the precaution to appear before Elizur Goodrich, alderman and notary public of the city of New Haven, who certifies as follows:

> That in said city on the twenty-eighth day of October, one thousand, seven hundred and ninety-three, Eli Whitney, of the County of Worcester, in the Commonwealth of Massachusetts, now residing in this city, personally appeared before me, the said Alderman and Notary, and made a solemn oath. That he does verily believe that he, the said Whitney, is the true inventor and discoverer of the machine for ginning cotton, a description whereof is hereto annexed by me, the said Alderman and Notary, by my seal Notorial, and that he, the said Whitney, verily believes that a machine of similar construction hath never before been known or used.[3]

A long, carefully detailed description, including alternative methods of constructing certain parts, was given "under five divisions corresponding to its five principal parts, viz: 1, Frame; 2, The Cylinder; 3, The Breastwork; 4, The Clearer; 5, The Hopper."

Whitney closes his description with the following statement:

> The foregoing is a description of the machine for cleansing cotton alluded to in a petition of the subscriber, dated Philadelphia, June 20th, 1793, and lodged in the office of the Secretary of State, all alleging that he, the subscriber, is the inventor

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[2] Amer. Hist. Rev., vol. 3, p. 99, 1897.

[3] Tompkins, D. A., Cotton and cotton oil, p. 460, 1901.

of the said machine, and signifying his desire of obtaining an exclusive property in the same.[4]

According to law a model was required for deposition in the Patent Office, and on November 16, 1793, Thomas Jefferson wrote to Whitney at New Haven, as follows:

> GERMANTOWN, *Nov. 16, 1793.*
>
> SIR:
>
> Your favor of Oct. 19 enclosing a drawing of your cotton gin was received on the 6th inst. The only requisite of the law now uncomplied with is the forwarding of a model, which being received, your patent may be made out and delivered to you immediately. As the State of Virginia, of which I am, carries on household manufacture of cotton to a great extent, as I also do myself, and one of our great embarrassments is the cleaning the cotton of the seeds, I feel a considerable interest in the success of your invention for family use. Permit me, therefore to ask information from you on these points: Has the machine been thoroughly tried in the ginning of cotton, or, is it yet but a machine of theory? What quantity of cotton has it cleaned on an average of several days, and worked by hand, and by how many hands? What will be the cost of one of them to be worked by hand? Favorable answers to these questions would induce me to engage one of them to be forwarded to Richmond for me.
>
> Wishing to hear from you on the subject, I am, Sir,
>
> Your most obed't servant
>
> TH. JEFFERSON.[5]

The personal interest shown by Jefferson prompted Whitney to answer his questions on November 24, 1793, in the following words:

> It is about a year since I first turned my attention to constructing this machine, at which time I was in the State of Georgia. Within about ten days after my first conception of the plan, I made a small, though imperfect model. Experiments with this encouraged me to make one on a larger scale; but the extreme difficulty of procuring workmen and proper material in Georgia prevented my completing the larger one until sometime in April last. This, though much larger than my first attempt, is not above one-third as large as the machines may be made with convenience. The cylinder is only 2 feet 2 inches in lengh and six inches in diameter. It is turned by *hand*, and requires the strength of one man to keep it in constant motion. It is the stated task of one negro to clean 50 weight (I mean 50 pounds after it is separated from the seed), of the green seed cotton per day.[6]

It is evident that Whitney was delayed in preparing the model for the Patent Office, as the patent was not issued until March 14, 1794. All of this time Whitney was in New Haven.

It is a matter of importance and of more than mere historical interest to know what this model was like, and exactly what mechanical devices were shown on it. As already stated, the United States Patent Office was destroyed by fire on December 15, 1836, including all models, drawings, and specifications of the patents which had been issued up to that time.

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[4] Tompkins, D. A., Cotton and cotton oil, p. 459, 1901; Wailes, B. L. C., Report on Agriculture and Geology of Mississippi, p. 369, 1854.

[5] Papers New Haven Colony Hist. Soc., vol. 5, p. 109, 1894.

[6] Amer. Journ. Sci. and Arts, vol. 21, p. 212, January 1832.

But for two fortunate circumstances we might never have known the exact specifications and claims of Whitney's patent, or the mechanical features shown in his original model, deposited in the Patent Office early in 1794. During the 10 years between 1795 and 1805, 24 suits for infringement of his patent rights were instituted in the United States District Court at Savannah, Ga. In the suit against Arthur Fort and John Powell entered in 1804, a copy of the schedule of specifications and a sheet of drawings were filed with the court. This copy was certified to by James Madison, Secretary of State, April 27, 1804, and is still a part of the court records at Savannah. The papers and the drawings were republished by D. A. Tompkins in 1901,[7] and again by Chas. Bennett in 1933.[8]

The other record describing and illustrating Whitney's invention was printed 19 years later, but still 9 years before the fire which destroyed the original model and patent papers. John S. Skinner, the editor of the American Farmer, in 1823 published the following statement:

> When we received the following account of improvements made on cotton gins, by Dr. Rush Nutt, near Petit-Gulph, Mississippi, we applied to Wm. Thornton, Esq.[9] of Washington City for a description of Whitney's cotton-gin from the Patent Office, that we might place before our readers a complete view of so important a machine and enable *all of* them to understand the nature of the reported improvements.[10] [See pl. 1.]

Editor Skinner then gives a short description of Whitney's gin, much less detailed than the very full description in the schedule filed in 1804 in Georgia, and a wood cut of the model in the Patent Office. This illustration does not indicate that the model was equipped with circular saws. The "cylinder" is described in the following words:

> Cylinder is of wood, its form is perfectly described by its name, and its dimensions may be from six to nine inches in diameter, and from two to five feet in length * * *. The surface of the cylinder is filled with teeth, set in annular rows, which are at such a distance from each other, as to admit a cotton seed to play freely in the space between them. The space between each tooth in the same row, is so small as not to admit a seed, nor half a seed to enter it. These teeth are made of stiff iron, driven into the wood of the cylinder, the teeth are inclined in the same way, and in such a manner, that the angle included between the tooth, and a tangent drawn from the point, into which the tooth is driven, will be about 55 or 60 degrees * * *.[11]

According to an act of Congress passed March 3, 1837, the Patent Office was authorized to expend $100,000 in restoring the specifications, drawings, and models of the burned patents, by obtaining duplicates of them from the persons possessing the originals.

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[7] Tompkins, D. A., Cotton and cotton oil, pp. 444–462, 1901.

[8] Bennett, Chas., Cotton and Cotton Oil News, vol. 34, pp. 4–10, 44–47, Apr. 1, 1933.

[9] Dr. Thornton was the first Commissioner of Patents and was appointed by Thomas Jefferson to relieve the Secretary of State of the rapidly increasing responsibilities of the Patent Office.

[10] Amer. Farmer, vol. 4, pp. 380–381, Feb. 21, 1823.

[11] Idem.

The models destroyed were about 7,000 and the records covered about 100,000 inventions. The work of restoration continued for 12 years, and something over $88,000 was expended out of the amount allowed. On page 125 of volume 1 of the Restored Patents, there is a record of the Whitney patent of March 14, 1794, entered in the book on May 2, 1841. It opens with a certificate by James Madison, Secretary of State, dated November 26, 1803, and reading in part as follows:

> I certify, that the annexed writings are true copies of a Patent granted to Eli Whitney on the 14th day of March, in the year one thousand seven hundred and ninety-four, and of the Specifications annexed thereto, compared with the Record thereof, and with the original Specification, remaining on file in the office.

Then, after writing in a copy of the grant of the patent, signed by George Washington, and the certification by the Attorney General, William Bradford, there appears this paragraph:

> The schedule referred to in these Letters Patent & making part of the same, containing a description in the words of the said Eli Whitney himself of an improvement in the mode of Ginning Cotton.

"A Short Description of the machine invented by the Subscriber" occupies part of page 126 and page 127. This is in the same wording as the "Short Description" furnished to the American Farmer, by Wm. Thornton in 1823.[12]

D. A. Tompkins, when publishing the detailed description taken from the records of the Georgia Circuit Court, already referred to,[13] printed in adjoining columns for comparison, the "Short Description" which he copied from volume 1 of the Restored Patents in the Patent Office. He called the "Short Description" the "Substituted Patent" and questioned its validity because of the following paragraph, which on page 128 closes the "Short Description":

> There are several modes of making the various parts of this machine, which together with their particular shape and formation are pointed out and explained in a Description with Drawings, attested as the act directs and lodged in the office of the Secretary of State.

This paragraph also accompanies Commissioner Thornton's description, furnished in 1823.

On May 2, 1841, there was also copied into volume 1 of the Restored Patents, on pages 85 to 93, the already mentioned long description, in detail, of the Whitney invention, closing with the certificate of Elizur Goodrich, dated October 28, 1793. It is introduced with a certificate by James Madison in practically the same wording as that already quoted as introducing the wording of the patent granted by Washington and the "Short Description", but in this case the date is given as November 25, 1803, instead of November 26. This detailed description, copied in longhand into the volume in 1841, is identical with that published by Tompkins from the Georgia Circuit Court records and certified by James Madison on April 27, 1804.[14] The Patent Office record on pages 85 to 93, however, is plainly labeled: "*Not patented,*" and this description, evidently for this reason, seems never to have been referred to before. In the opinion of the writer, both documents, as restored, are necessary to complete the restoration of the Whitney patent of March 14, 1794. When these two documents are taken together, the long description and drawings declared before Notary Goodrich, and supplementing the condensed description filed with the patent grant itself, it will be seen that the "several modes of making the various parts of this machine * * * pointed out and explained in a description with drawings," which so puzzled Tompkins, are undoubtedly the alternatives given in the long description and applied only to the formation of the breastwork and brush cylinder.

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[12] Idem.

[13] Tompkins, D. A., Cotton and cotton oil, pp. 444-462, 1901.

William Scarborough, of Georgia, in his sketch of the life of the late Eli Whitney, published in 1832, gives a clear description of the cylinder, the principal part of Whitney's machine. He begins his account of Whitney's activities with the following paragraph:

> The details which follow are wholly derived from memory unassisted by note or memorandum of any kind; but they will be found substantially correct. That which took place anterior to May 1799, when the first of Mr. Whitney's gins was put in operation was derived from a much esteemed and lamented friend,[15] who was the family physician and intimate friend of Mr. Phineas Miller, and that of subsequent date occurred under the eye, or to the knowledge of the writer of this sketch.[16]

In telling of Whitney's very first trial model, Mr. Scarborough says:

> It consisted of a wooden cylinder, similar to the barrel of an organ, with bent teeth inserted in straight rows, between which thin slats of iron were placed forming narrow grooves through which the teeth on the cylinder could revolve thereby tearing off the cotton from the seed, which dropped below.

Scarborough continues with the story of Whitney's experiments on the Greene plantation, and again mentions the details of the cylinder.

> Mr. Whitney proceeded to the North to have more perfect models prepared, and to secure the patent right in the names of Miller and Whitney, which was accordingly done. The experiment was there renewed with different cylinders, the one with the bent teeth before described, and the other with the annular saws as Mr. Whitney so termed them. His friends, among the number of whom was Mr. Hillhouse, (United States Senator from Connecticut), seemed to be of the opinion that the cotton ginned by the former (the bent teeth) had a better appearance than that ginned by the latter. The first large gin set into operation by horse-power was accordingly made with the bent teeth; and if the writer of this sketch

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[14] Tompkins, D. A., Cotton and cotton oil, pp. 444-462, 1901.

[15] Dr. Lemuel Kollock.

[16] Southern Agriculturist, vol. 5, p. 398, August 1832.

> is not misinformed, it is still in existence at Mulberry Grove. But Mr. Whitney, himself, from greater mechanical knowledge, or some other unknown cause, deposited in the Patent Office the model with the annular saws.[17]

His last statement concerning the saws contradicts Dr. Thornton's description and drawing of the Patent Office model.

III. MODELS OF THE WHITNEY GIN

Several small models of the "Cotton Cleaning Machine" were made by Whitney himself, or under his direction, before 1800. Some of these models are still in existence, and it is the desire of the writer to record some bits of information about them before their pedigree is lost.

The most important model is now exhibited in the Textile Division of the United States National Museum (pl. 2). It was deposited by Eli Whitney, Jr., in December 1884 in response to a request from the Secretary of the Smithsonian Institution, Spencer F. Baird. In transmitting the model, Mr. Whitney wrote:

> We have a model, one of 5 made by my father * * *. There have been 2 models burnt up in the Patent Office at Washington. One in 1836 and 1 in 1870 odd * * *. We have sent to your address the Model Cotton Gin invented and made by my father. It would have been sent before, but had to be repaired and I have been confined to the house by illness for a few weeks. Please have it put in a prominent position. Enclosed please find a little history of the invention which you can have printed or written on a card * * *. It should be of interest to every Southerner.

He thus accounts for three of the five models mentioned in his letter. Dr. Edward Craig Bates, in his Story of the Cotton Gin, publishes a letter written him by Eli Whitney, Jr., in 1890.

> The photograph sent you of the Cotton Gin is from a small model, say 18 x 12, made under my father's direction about ninety years ago. There are but two of these models now in existence; one at the Smithsonian and the one in my possession.[18]

An excellent account of the method of ginning cotton before the invention of the Whitney gin, and a description of Whitney's invention and several models, are given by Benjamin Leonard Covington Wailes, Geologist of Mississippi, in 1854.

> I have had the rare opportunity of examining critically, in all its parts, an early model of the gin on a small scale constructed under Mr. Whitney's direction, and which is now exhibited in the Crystal Palace, in New York.
>
> The model shows the progress of the invention as elaborated in the ingenious mind of its author, and his first idea seems to have been that of *carding* the lint or fiber from the seed, rather than that suggested by the use of the saw. The cylinder in the model is divided into three parts; one-third of it at the left end is armed with stout, crooked wires driven in, flattened at the sides, and the ends brought to an edge, as shown in Plate VII, fig. 5. The middle third of the cylinder

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[17] Southern Agriculturist, vol. 5, p. 399, August 1832.

[18] New England Mag., n. s., vol. 2, p. 293, May 1890.

is provided with a similar arrangement of wires, not flattened as in the first, but pointed as in fig. 4. And the remainder of the cylinder is mounted with the circular saw rags, similar to those now in use.[19] [See pl. 3.]

Wailes' description of this model, with its three kinds of teeth, fits perfectly the model now in the National Museum. The model mentioned by Eli Whitney, Jr., in his letter to Mr. Bates as being "retained by me" was publicly exhibited in 1886 during the celebration of the centenary of the town of Hampden, Conn.,[20] and was placed in the Museum of the New Haven Colony Historical Society by Miss Elizabeth Day Whitney, about 1926, after the death of her father, Eli Whitney, 3d, where it is now. The writer examined this model in July 1937 and found it to be almost identical in shape and size with the one in the National Museum, except the 15 annular rows of teeth on the cylinder, which are all of wire, bent and sharp-pointed like those described by Wailes.

To keep the record straight for future investigators of this subject, I wish here to record that, according to a letter from Prof. Joseph Wickham Roe, "a Chinese copy" of this model in New Haven was made in 1936 under his direction for the Museum of Science and Industry in New York City.

Another model of the Whitney gin of the same size and materials as the one first described is also in the collection of the National Museum. This model was among the collection of 155,000 patent models placed in storage by the United States Patent Office in 1908 and dispersed in 1926 in accordance with an Act of Congress. It was retained for the National Museum by this author, along with several thousand models of other patents. The model appears to be of a later date than the two other similar models, constructed on the same scale, already mentioned. It certainly was not constructed by Eli Whitney, Sr., for it shows a mechanical defect that he would never have passed. The crank for operating the model is attached to the end of the brush cylinder, instead of the cylinder carrying the gin teeth, which moves at only one-sixth of the speed of that of the brush cylinder. In the Record Room of the Patent Office are two large sheets of original drawings made in 1840 which exhibit the details of the above-mentioned model, including the crank in the wrong position. It does not seem possible to tell whether the model was made from the drawing, or vice versa.

According to the numbering of the small detail drawings on the two sheets, there should be a third sheet, as figures 7, 8, 9, 10, 13, 15, 16, 17, 18, and 19, are missing. This discrepancy was pointed out by Bennett in 1933.[21] [See pl. 4.]

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[19] Report on the Agriculture and Geology of Mississippi, pp. 159-160, 1854.

[20] Hampden Centenary, 1786-1886, pp. 112, 281, 1886.

[21] Bennett, Chas., Cotton and Cotton Oil News, vol. 34, p. 6, Apr. 1, 1933.

When this author first read the letter of Eli Whitney, Jr., stating that his father had made five models of the gin before 1800, he wondered why so many were made when only one was needed to be filed with his application for a patent. A study of Whitney's letters suggests a solution of the question.

Two suits for infringement of the patent were filed by Miller and Whitney in 1795 in the Georgia Circuit Court. In Whitney's letter to his partner, Miller, dated December 25, 1795, Whitney wrote:

> I go to New York soon. After my return I shall set about the examplifying models. I wish you would inform me when the suit will come to trial and of the manouvers of my enemies.[22]

Scarborough describing a court scene during the trial of one of the many suits for infringement, says:

> At the trial which took place at Louisville, Georgia, in the Federal Circuit Court, the writer of this sketch was present. Mr. Whitney entered the Court with a small package, enveloped in a silk handkerchief, which had the appearance of containing books, this he carefully deposited under the court table. The testimony above alluded to being read, it had the semblance of being conclusive in its effect. When it became necessary to rebut it to the Court, Mr. Whitney claimed the privilege, which was granted, of doing it, as being best calculated to give the necessary mechanical explanations. He took his package from under the table, and opening the handkerchief, presented to view an exquisitely beautiful model of his gin about fourteen or fifteen inches in length, with several handfuls of seed cotton. He handed both up to the judge, and spreading out the silk handkerchief to prevent the escape of the ginned cotton, desired the judge to turn the crank, which he seemed to do with great delight, and in a very few seconds the cotton separated from the seed, was gathered up and pressed together in the hand. Mr. Whitney then inquired of the judge and jury if it was not in that state the cotton was exported for the purpose of manufacture either in England or Ireland? Which being assented to; he handed the ginned cotton to the judge, requesting him to strive and force the cotton again between the slats, which it was found impossible to do without breaking the model all to pieces. Thus by the most conclusive occular demonstration, he proved to the satisfaction of every one present, that the machine used in Europe could have no sort of affinity, let alone identity, with his invention.[23]

It is a matter of record that one of the reasons given by the State of South Carolina for not paying Whitney the sum agreed upon for the use of his patent throughout the State was that he had not deposited two models of his gin as stipulated in the contract. Whitney's partner writes to Paul Hamilton, Comptroller of South Carolina, on January 19, 1803:

> I have just received a letter from Mr. Whitney who expressly says that he did not stipulate to deliver the models by the first of September, but on the contrary that he refused to be bound by such a condition, but that he expected to make them as soon as the pressure of his other business would allow * * *. What then could have been fairly expected from an inspection of these two models? Nothing more surely than a more neat and handsome method of

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[22] Amer. Hist. Rev., vol. 3, p. 104, 1897.

[23] Southern Agriculturist, vol. 5, p. 401, Aug. 1832.

> constructing a well known machine on a principle which has been in use for eight years, than could be expected from the mechanics who are in the habit of constructing these machines in the upper country.[24]

Whitney later did prepare the models demanded, according to Professor Olmsted:

> Two models of a gin were also furnished by Mr. Whitney, executed we are told in a most superior and masterly manner, and far surpassing in excellence, any machinery of the *kind* ever before seen; they were of metal and so nicely, and substantially made, that it is hardly possible for them to get out of order; and they worked with such ease, that when the hopper of a forty Saw Gin was filled with cotton, the labor of turning it was not greater than that of turning a common grindstone. The models were highly approved and the Legislature did not hesitate to do justice to the ingenious inventor, according to their original agreement * * *.[25]

One of these models was described by Wailes in 1854 as being constructed on an iron frame, "with 40 saws, 6¾ inches in diameter, separated by block tin or pewter castings." [26] Efforts have been made to determine whether or not these official gin models are now in existence, but so far without success.

IV. EARLY ACTIVITIES OF WHITNEY IN GEORGIA

There have been numerous claims, based on local traditions, that Whitney established and operated his first gin at this or that place, and it has even been claimed that Whitney's original workshop has been found in what was called in his day, the "Upper Country." Prof. M. B. Hammond, who published many of Whitney's letters from correspondence and papers lent to him by Eli Whitney, Jr., says that Whitney did not leave the Greene plantation at Mulberry Grove except to go to Savannah, 12 miles away, to procure materials and cotton.

I have already mentioned Scarborough's statement that "The first large gin set into operation by horsepower * * * is still in existence at Mulberry Grove."[27] Maj. Nathaniel Pendleton stated that he was one of the first persons who saw Whitney's gin when it was first put in motion; that soon after 1793 "a machine house was put up at Mulberry Grove by Mr. Phineas Miller and several of these machines were worked in it by cattle, which I frequently saw." [28]

The Georgia Gazette for March 6, 1794, printed the following advertisement:

> COTTON GINNING
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> The subscriber will engage to gin in a manner equal to picking by hand, any quantity of the green seed cotton, on the following terms, viz. for every five

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[24] Amer. Hist. Rev., vol. 3, p. 119, 1897.

[25] Amer. Journ. Sci., and Arts, vol. 21, p. 226, January 1832.

[26] Report on the Agriculture and Geology of Mississippi, 1854, pp. 160–161.

[27] Southern Agriculturist, vol. 5, p. 399, August 1832.

[28] Amer. Hist. Rev., vol. 3, p. 126, 1897.

pounds delivered to him in the seed he will return one pound of clean cotton fitted for market.

For the encouragement of planters he will also mention that ginning machines to clean the green seed cotton on the above terms will actually be erected in different parts of the country before the harvest of the ensuing crop.

PHINEAS MILLER,
Mulberry Grove, Near Savannah.

MARCH 1, 1794.[29]

This was 2 weeks before Whitney, who was then in New Haven, was granted his patent. Miller, his energetic partner, who had furnished the money for launching the invention, proceeded to purchase water-power sites and set up Whitney gins as fast as Whitney could turn them out from his factory in New Haven.

Professor Olmsted states that "by 1796 Miller and Whitney had 30 gins in eight different places in the State of Georgia."[30] Some of these were run by water power and others were turned by horses or oxen.

Phineas Miller, in a letter to Whitney dated September 28, 1797, says:

> In taking the titles to the place which I received on the Partnership account from Durkee, I have as yet let them stand in my name, specifying in my books that they were held in trust, on account of making a legal reconveyance should it be required.[31]

Miller's reference "to the place which I received on the Partnership account from Durkee" was the site on Upton Creek in Wilkes County, Ga., where he located a gin operated by the water power. After Miller's death in December 1803, the records show his widow transferred the power site to a company of local people who operated a spinning mill there for a few years.

Other historians have mentioned "the Partnership account from Durkee," in the following quotations telling of the water-power gin operated on this spot:

> I rode, a few days since, six miles below this place (Washington, Ga.) to see my old friend Thos. Talbot, and his kitchen and barn. Mr. Talbot is 83 years old, in full possession of his faculties, and is living where he settled 62 years ago. Whitney, the inventor of the Cotton Gin, settled a plantation adjoining him, on which he placed one of his gins; the first that was used in Wilkes County; perhaps the first in the State. He and his partner Durkee, erected a gin house, and a large cotton house. The latter to hold the cotton they expected to receive from customers to gin * * *. Durkee, Whitney's partner, being dissipated and inattentive to business, he sold out his place, and the gin and cotton house coming into the possession of Mr. Talbot, he moved them to his place. The former is now his kitchen * * *. The cotton house makes a large and commodious barn. (Judge GARNET ANDREWS, 1852.)[32]

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[29] Georgia Hist. Quart., vol. 3, p. 146, September 1919.

[30] Amer. Journ. Sci. and Arts, vol. 21, p. 217, January 1832.

[31] Amer. Hist. Rev., vol. 3, p. 110, 1897.

[32] Southern Cultivator, vol. 10, October 1852.

> In the immediate neighborhood of Old Smyrna Church, on the property which once belonged to the Estate of Governor Matthew Talbot, stands an old structure around which centers a world of historic interest. It was erected by the famous inventor, Eli Whitney, in association with his partner for the time being, a man named Durkee; and it was built to house what was probably the first cotton gin erected in the State of Georgia.
>
> (LUCIAN LAMAR KNIGHT, 1913.) [33]
>
> It is an interesting fact, that one of the first if not the very first, cotton gins ever operated in Georgia, or in the world, was the one operated by Eli Whitney, the famous inventor, in Wilkes County, near Smyrna Church. The original building, though removed a short distance from the site upon which it was erected, is still standing on the Burdett place near Smyrna.
>
> (OTIS ASHMORE, 1917.) [34]

A correspondent, signing himself "A Small Planter", writes to John D. Legare, editor of the Southern Agriculturist, on October 22, 1832, as follows:

> * * * By the statement of Mr. "S" the first one of Miller & Whitney's was not completed till May 1799, whereas in the year 1797, to my certain knowledge, Mr. Miller had one in full operation on his plantation on Upton's Creek, Wilkes County, Ga.
>
> I visited Georgia the fore part of the same year (1797) and after riding over several counties, I went to see a gentleman in the upper part of Wilkes, to whom I had letters of introduction * * *.
>
> Some months after this I went to see Mr. Miller's gin on Upton's Creek (it also went by water) and found, upon examination, that the picking implements were straight wire-teeth drawn into a wooden cylinder, and afterwards sharpened with a file. They would have answered the purpose tolerably well could they have been permanently fastened to the cylinder, but the impetus of the operation was too great for the substance they were attached to, which giving away, the teeth would fly out in the midst of the work and occasion considerable trouble and loss of time * * *.[35]

If Professor Olmsted's statement is true: "That by 1796 Miller and Whitney had 30 gins in eight different places in the State of Georgia," it would not be surprising for localities other than Washington, in Wilkes County, to make claim as the first place of operation of a Whitney gin.

Augusta, in Richmond County, is one of these, as the following quotations will indicate:

> During the past winter the writer visited the spot where Whitney made his experiments with his cotton gin. Upon a sluggish stream that is known as Rocky Creek which flows into the Savannah River a few miles below Augusta, Ga., stands a deserted wooden mill building with its crumbling wooden tub wheel in a decayed wheel pit. Near by is a broken dam and a cane brake which borders upon a swamp where the long flowing moss hangs drooping from the trees. The spot is interesting only as a place where Whitney made experiments and operated his first cotton gin. (M. F. FOSTER, 1899.) [36]

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[33] Georgia's Land-Marks, Memorials and Legends, vol. 1, p. 1052, 1913.

[34] Georgia Hist. Quart., vol. 1, p. 64, 1917.

[35] Southern Agriculturist, vol. 5, p. 626, 1832.

[36] Trans. New England Cotton Manuf. Assoc., No. 67, p. 152, 1899.

> It is a fact of no small interest in connection with the history of Augusta that Whitney manufactured his gins at a little factory, the power of which was furnished by the little Rocky Creek on the plantation of the late Mr. John Phinizy, now almost included in the present boundaries of the city. (From address of Mayor Joseph B. Cumming on occasion of Celebration of Municipal Centennial of the City of Augusta.) [37]
>
> After the gin was invented, Whitney established his machines in various places in Georgia for the purpose of buying and ginning cotton. One of these was near Augusta, about two miles south of the city. The dam is still seen which held the water to furnish the power. (Lucian Lamar Knight, 1914.) [38]

An arrangement in chronological order of the published correspondence of Eli Whitney and documented statements of his place of residence, from the fall of 1792 until the middle of 1805 shows plainly that Eli Whitney himself carried on his activities and experiments in New Haven except for a few very brief periods at Mulberry Grove, or when he was engaged with law suits at Savannah. He could not in person have carried on the activities attributed to him by local traditions in numerous localities. These activities doubtless were carried on by Phineas Miller, acting for the firm of Miller & Whitney, until his death on December 7, 1803.

V. SUMMARY

A recent study of some of Eli Whitney's correspondence with his father, his partner, and others; the rediscovery of numerous early accounts of his activities in the South; and the recent examination of several original models of the gin, have thrown some new light on the history of Whitney's famous invention. They indicate several mistakes and misconceptions in documents hitherto believed to be correct.

In view of the destruction of the original patent papers and the original working model which was filed with Whitney's application for his patent, it is believed worth while to redescribe that model, and to point out that accurate copies of the patent and specifications of the machine are still in existence.

A careful examination of these documents does not disclose the use of gin saws, or of a cylinder built with teeth cut in plates of metal.

It is pointed out that what is understood to be the "Whitney patent" is a series of steps and documents which need to be taken together and considered as a whole to determine just what was covered by a patent granted to Eli Whitney on March 14, 1794. These steps may be arranged in the following order:

1. First application for a patent made to Thomas Jefferson, Secretary of State, June 20, 1793.
2. Forwarding of a drawing to Jefferson, October 19, 1793.

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[37] Georgia Hist. Quart., vol. 1, p. 228, September 1917.

[38] Georgia's Land-Marks, Memorials and Legends, vol. 2, p. 968, 1914.

3. Declaration before the New Haven notary public, Elizur Goodrich, October 28, 1793, that he, Eli Whitney, believed himself to be the original inventor of a machine to separate the green seed cotton from its seeds, and the filing with the notary public of a detailed description of the invention.

4. The filing of a working model of the machine as requested in Jefferson's letter of November 16, 1793.

5. The filing by Whitney of a description of his invention written in his own words.

6. The granting of the patent signed by George Washington on March 14, 1794, for an exclusive right to the use and sale of his invention for 14 years from November 6, 1793.

It has been shown that before the fire of December 15, 1836, when the originals of all these documents (except possibly the first and the third) were destroyed, certified copies or descriptions were filed elsewhere. Of the documents above mentioned, copies of the third and sixth were filed in the Circuit Court at Savannah, Ga., in 1804; the fifth document and a drawing of the model were published in a periodical in 1823; the third, fifth, and sixth documents were in 1841 copied at the Patent Office into the first volume of Restored Patents apparently from copies on file in the Office of the Secretary of State, the third document, however, being labeled "Not patented" in the Patent Office copy.

It has been pointed out that several models of Whitney's gin are in existence, that two of these are from a group of five models made by Whitney himself, or under his direction, before 1800. These two models have been described and compared with an illustration of the original model made by Whitney and filed with his application for his patent at the end of 1793. This illustration was published in 1823, 13 years before the original model was destroyed by fire.

Whitney's partner, Phineas Miller, advertised early in 1794, even before Whitney was granted his patent, that he would "engage to gin in a manner equal to picking by hand, any quantity of the green seed cotton," and promised that gins for this purpose would "actually be erected in different parts of the country before the harvest of the ensuing crop."

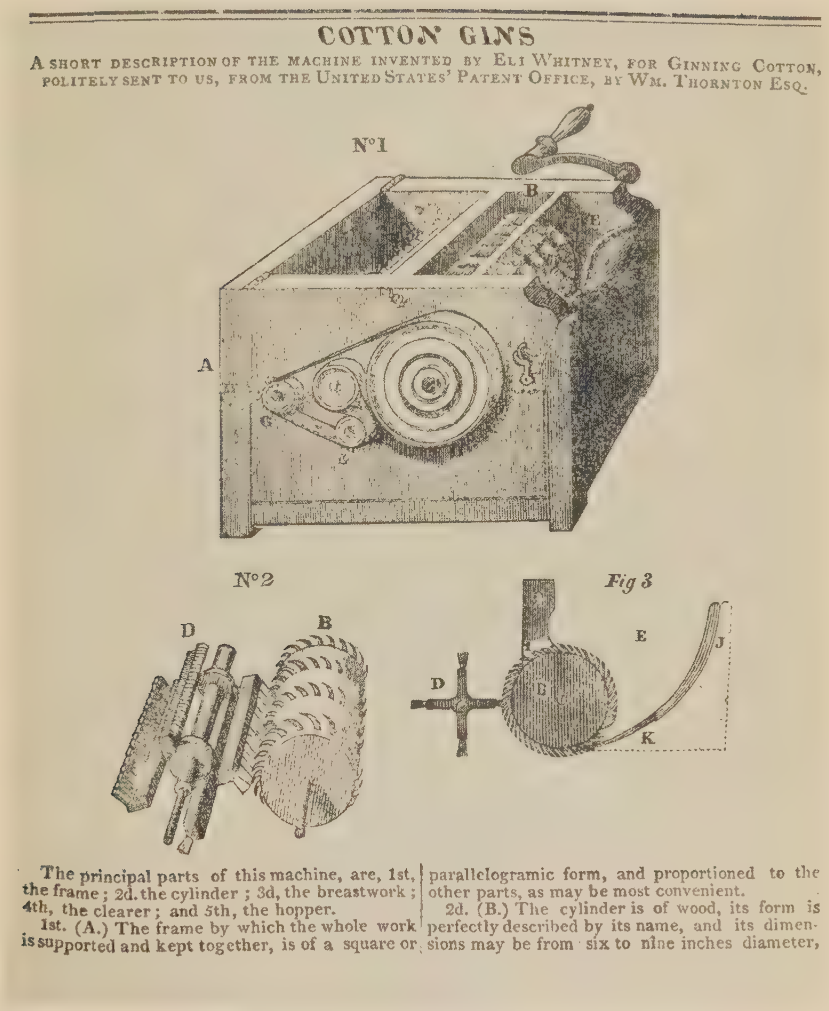
This energetic partner did carry out his promise, and while Whitney was in New Haven, Conn., building gins as fast as he could, Miller sought out water power sites at points where the green seed cotton was being cultivated. These sites were usually purchased for the partnership, but sometimes the titles to the properties were recorded in his own name, as one of his letters to Whitney indicates. Within 2 years he had 30 gins in operation at 8 different places in Georgia. As time went on, rivalry developed among local points, which now claim the distinction of being the place where the Whitney gin was first operated.

In spite of the statements in Whitney's correspondence that his experiments were carried on at the Greene plantation, near Savannah, Ga., and at New Haven, Conn., two localities in particular, Washington, Ga., in Wilkes County, and Augusta, Ga., in Richmond County, have been cited as the spot where Whitney made his experiments with his cotton gin.

A study of Whitney's correspondence and other authentic documents conclusively proves that, with the exception of a few months in the early part of 1793, when he was without funds and dependent upon the hospitality of his hostess, the widow of Gen. Nathaniel Greene, Whitney could not possibly have carried on experiments in ginning cotton and gin building at points distant from Mulberry Grove. Phineas Miller's letters, written to Whitney at New Haven, appealing for more gins to take care of the enormous increase in the production of the green seed cotton, are proof that Whitney did not have the time to carry on experimental work in upper Georgia.

GENERAL WORKS CITED

1. Olmsted, Denison
   1832. Memoir of the life of Eli Whitney, Esq. Amer. Journ. Sci. and Arts, vol. 21, No. 2, pp. 201–254, January.
2. Scarborough, William
   1832. Sketch of the life of the late Eli Whitney with some remarks on the invention of the saw gin. Southern Agriculturist, vol. 5, No. 8, pp. 393–403, August.
3. Hammond, Matthew Brown
   1897. Correspondence of Eli Whitney relative to the invention of the cotton gin. Amer. Hist. Rev., vol. 3, pp. 90–127, October.
4. Bates, Edward Craig
   1890. Story of the cotton gin. New England Mag., n. s. vol. 2, pp. 287–293, May.



COTTON GINS

A SHORT DESCRIPTION OF THE MACHINE INVENTED BY ELI WHITNEY, FOR GINNING COTTON, POLITELY SENT TO US, FROM THE UNITED STATES' PATENT OFFICE, BY WM. THORNTON ESQ.

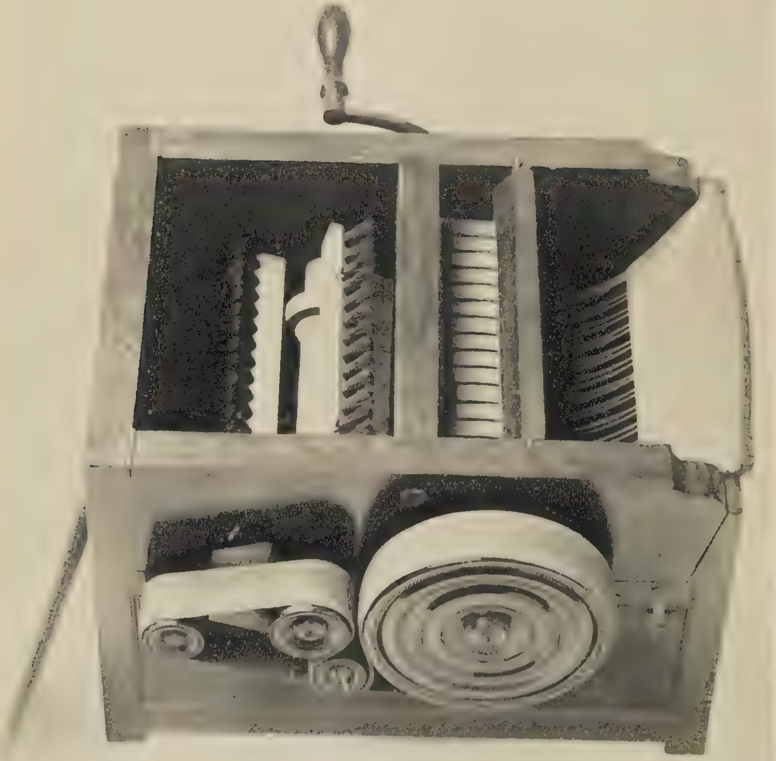
N°1
B
E
A
G
G
N°2
D
B
Fig 3
E
J
D
D
K

The principal parts of this machine, are, 1st, the frame; 2d. the cylinder; 3d, the breastwork; 4th, the clearer; and 5th, the hopper.

1st. (A.) The frame by which the whole work is supported and kept together, is of a square or parallelogramic form, and proportioned to the other parts, as may be most convenient.

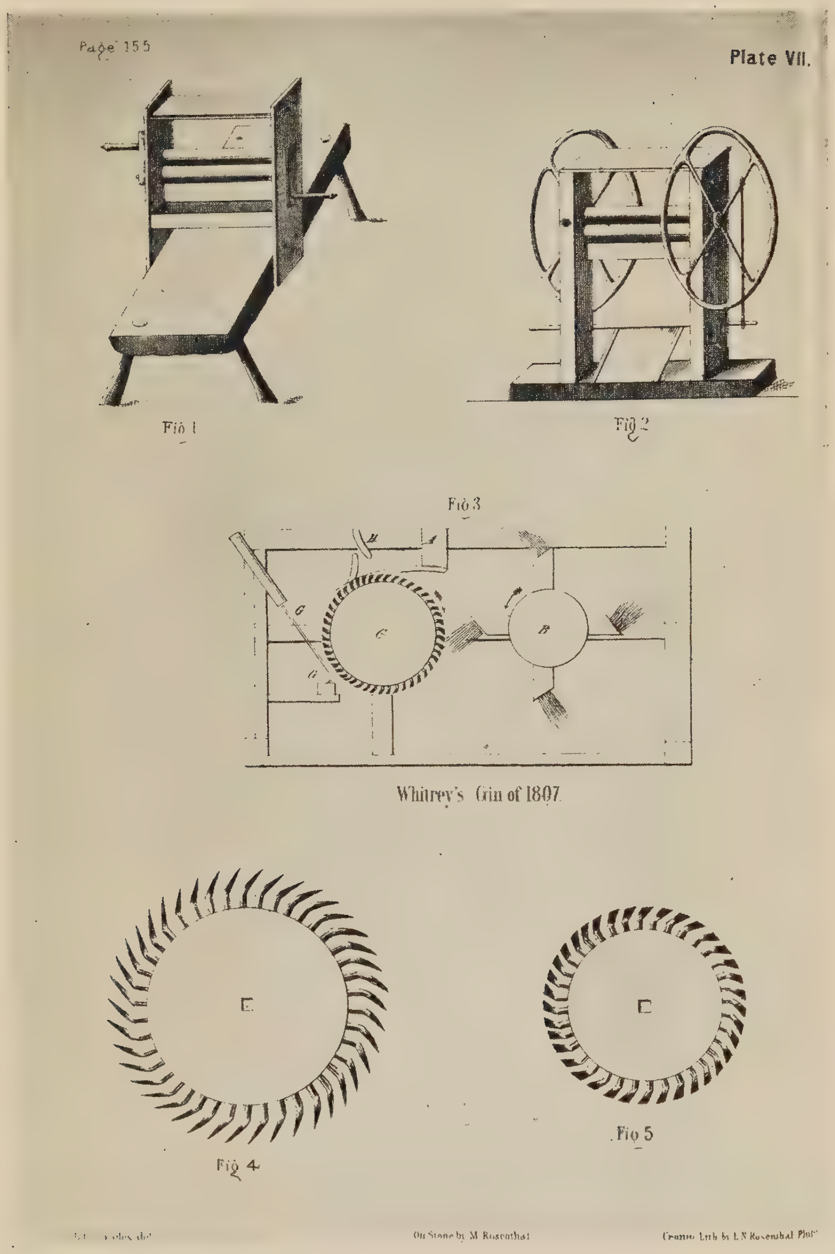
2d. (B.) The cylinder is of wood, its form is perfectly described by its name, and its dimensions may be from six to nine inches diameter,

PHOTOGRAPH OF PART OF PAGE 380, AMERICAN FARMER, FEBRUARY 21, 1823, VOL. 4, NO. 48.



MODEL OF THE WHITNEY GIN NOW IN THE U. S. NATIONAL MUSEUM, DEPOSITED THERE IN 1884 BY ELI WHITNEY, JR.

Model made by Eli Whitney before 1800.


Page 155
Plate VII.
Fig 1
Fig 2
Fig 3
B
A
G
C
B
G
Whitney's Gin of 1807
E
Fig 4
E
Fig 5
oles del
On Stone by M Rosenthal
Chromo Lith by L.N Rosenthal Phil.

REPRODUCTION OF PLATE 7, OPPOSITE PAGE 155, IN WAILES, B. L. C., REPORT ON THE AGRICULTURE AND GEOLOGY OF MISSISSIPPI, 1854.

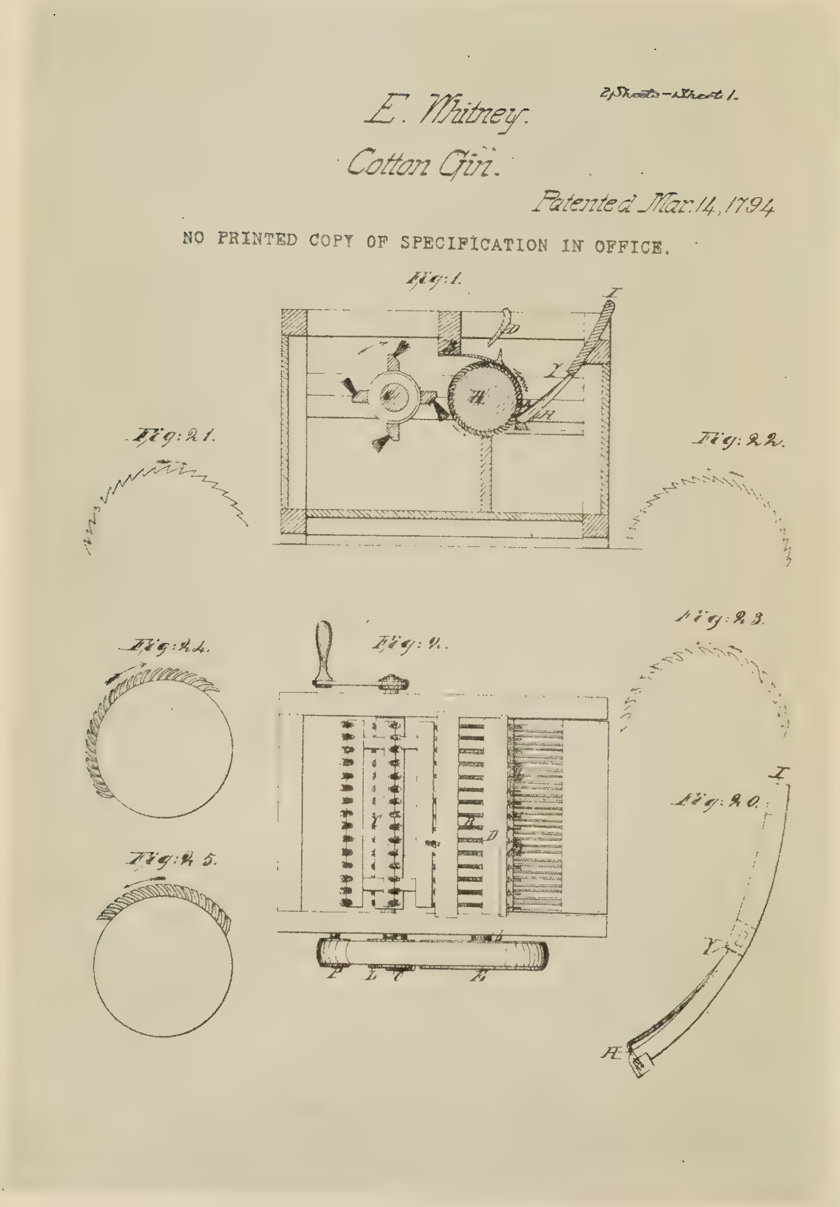

E. Whitney.
2 Sheets—Sheet 1.
Cotton Gin.
Patented Mar. 14, 1794
NO PRINTED COPY OF SPECIFICATION IN OFFICE.
Fig: 1.
I
D
Y
W
H
Fig: 21.
Fig: 22.
Fig: 23.
Fig: 24.
Fig: 2.
D
Fig: 25.
Fig: 20.
I
Y
H

PHOTO COPY OF THE DRAWINGS FURNISHED BY THE U. S. PATENT OFFICE TO ACCOMPANY SPECIFICATIONS OF ELI WHITNEY'S PATENT OF MARCH 14, 1794.

This photograph was supplied by Chas. A. Bennett and was used in his article in Cotton and Cotton Oil News, April 1, 1933. The original of this drawing, dated 1840, is on file in the Record Room of the U. S. Patent Office.

THE WORLD'S LONGEST BRIDGE SPAN[1]

By Clifford E. Paine

[With 4 plates]

The traveler approaching San Francisco by sea finds his ship heading for a mile-wide gap in the mountainous shore line. Passing through this natural gateway, which is known the world over as the Golden Gate, he sees before him a great expanse of water that extends 40-miles to the southward and 30 miles to the northward. On his right lies the city of San Francisco. On his left is marvelous Marin County with its delightful suburban communities—the gateway to scenic wonders of the Redwood Empire. Before him, straight across the bay on the far distant shore, lie the cities of Alameda, Oakland, and Berkeley. Directly above him is the Golden Gate Bridge, man's most recent victory in his conquest of nature's barriers to progress.

For many years the ferry boats have constituted the only means of transportation between these rapidly expanding communities. Improvement in highways and increased use of automobiles, coupled with the growth of the bay cities, brought forth the demand for a corresponding improvement in transportation facilities. In 1918 investigations were made and the feasibility of building a suspension bridge across the Golden Gate was established by Joseph B. Strauss. As a result of the movement then started, the city and county of San Francisco joined with five counties to the north in forming the Golden Gate Bridge and Highway District to build and operate the Golden Gate Bridge. Mr. Strauss was made chief engineer of the District, and a bond issue of $35,000,000 was voted in November 1930. Plans for the bridge were made by Strauss & Paine, Inc., and construction was started in January 1933. The bond issue was based on a construction cost of $27,165,000. The bridge has been completed with a construction cost about one-half of 1 percent under that estimate.

Traffic studies have indicated that during the first year of operation 2,000,000 cars will pass over the bridge and that the volume of traffic will possibly increase at the rate of about 5 percent per year during the first 10 years of service. The bridge has a capacity of 5,000 cars per hour, and it is expected that this will be fully utilized by holiday and week-end traffic from the very beginning.

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[1] Reprinted by permission, with slight revisions by the author, from Armour Engineer and Alumnus, vol. 2, No. 3, March 1937.

Having passed through the Gate, our traveler will now without doubt fix his attention on the magnificent structure under which he has just passed. He may have traveled the world over but nowhere has he seen a bridge of such magnitude or graceful beauty. At midspan it is 230 feet above the water, high enough to let any ship afloat pass underneath with plenty of clearance. It is a mile across, and there is only one pier in the water. That pier is only 1,100 feet from shore; it is 4,200 feet between the towers which support the cables and which in turn support the floor of the bridge. In all his travels he has not seen towers like these. The design gives confidence of strength and stability and at the same time gives that feeling of satisfaction most often inspired by structures that are architecturally correct. An officer of the ship, standing beside him, tells him that the tower tops are 750 feet above the water. The two cables which pass over the tops of the towers and end in massive blocks of concrete back on shore, are 36½ inches in diameter—the largest bridge cables ever made. Each cable is 7,650 feet long and contains 27,572 parallel wires about the size of a lead pencil. Eighty thousand miles of wire were required for the two cables—enough to encircle the globe more than three times at the Equator. Each cable has an ultimate tensile strength of 200 million pounds. Yes, it takes a pretty good anchorage at each end of the cable to withstand this pull. Fortunately, solid rock was found at each end, and big pockets were excavated in this rock to form a setting for the concrete anchorage blocks, each of which contains 30,000 cubic yards. You're right, there is a trick about fastening the cable to the anchorage. You see, the wires of the cable are grouped into 61 strands. Some distance in front of the anchorage a cast steel band is placed around the cable and between that point (called the "splay point") and the anchorage the strands "fan out," so that at the anchorage they are separated by 2½ feet or more. Each strand is there anchored to a pair of steel bars which extend back into the concrete for about 130 feet where they terminate in heavy steel girders.

Our friend realizes at a glance that the entire floor structure of the bridge is suspended from these huge cables. He can see at 50-foot intervals the steel ropes which hang down from the cables and attach to the stiffening trusses. At each point of attachment there are four parts of rope 2¹¹⁄₁₆ inches in diameter. The concrete roadway and sidewalks are carried directly on this suspended steel framework. There it hangs like a great hammock between the giant towers. How far will it swing sideways? That is a fair question.

The informative officer in his frequent passing through the Gate has been asked all kinds of questions about this unusual structure and is prepared with all the answers.

Under the effect of a broadside wind at 100 miles per hour, the bridge floor at midspan might swing 21 feet out to one side. Since winds in San Francisco rarely reach half this velocity and never have exceeded 60 miles per hour, it is quite probable that it will never be called upon to withstand such a strain. Yes, the floor moves up and down too with every change in temperature and load. A rise in temperature causes the cable to lengthen and consequently the sag increases. Obviously, the sag in the center span will be decreased by loading the side spans and increased by loading the center span. The most severe combinations of loading and temperature will cause the floor of the bridge at midspan to rise 10 feet above or fall 10 feet below its normal elevation. In order to accommodate these movements as well as the lengthening or shortening of the suspended steel structure, itself, special joints are provided where the floor of the suspended span joins the floor that is carried directly by the tower. These joints permit angular motion in horizontal and vertical planes combined with a longitudinal movement of 5 feet from one extreme to the other and they are so designed as to give a smooth riding surface across the joints under all conditions of load and temperature.

Does the cable slide over the top of the tower? No! The tower tops are pulled back and forth by the cables under the varying combinations of temperature and loading. Under normal conditions, that is, with temperature at 70° F., and no load on the span (other than its own dead weight), each tower is bent shoreward 6 inches. Now, if the temperature rises 40° and full live load is applied to the center span and the far side span only, the tower will be deflected channelward 18 inches. If the temperature drops 40° below the normal temperature of 70° F. and full live load is applied to the near side span only, the tower will be deflected shoreward 22 inches. In other words, the towers may be bent to and fro so that their tops move through a range of 40 inches in the longitudinal direction of the bridge. In a direction transverse to the bridge, the towers would deflect 12½ inches under the same wind load which would cause a 27-foot deflection in the center span.

Each tower receives from the two cables a total load of 123 million pounds. The concrete piers upon which the steel towers rest must carry this load plus the weight of the steel tower, which is 44 million pounds, or a total applied load of 167 million pounds. The San Francisco pier, allowing for buoyancy, weighs 560 million pounds, and therefore the total load on the foundation which supports the San Francisco pier and tower is 727 million pounds.

In design and construction the engineers were confronted with some unique problems. From the outset the construction of the

San Francisco pier was recognized as a major task. It was located 1,100 feet out from shore in water having an average depth of 65 feet. The site was exposed not only to the destructive ocean winds and waves, but also to tidal currents of 7 miles per hour. The difficulties were multiplied by the fact that the floor of the strait was bare rock and consequently it was difficult to anchor equipment and get a "toe hold." The completed pier would have to have the protection of a very substantial fender to guard against damage from derelicts or ships out of control. It was decided that this fender would be built as a part of the pier—a wall 27½ feet thick forming the circumference of the pier. It was conceived that this wall could be built first in small successive units so that as exposed surface to tides increased, the mass of previously placed wall would afford a corresponding increase in stability. The initial section could be placed by anchoring to the rock a steel form about 30 feet square. Divers could place forms around this frame and then the box thus formed could be filled with concrete. The initial unit in place, succeeding units could be built out in both directions, eventually encircling the whole pier site. The pier within the wall could then be completed with full protection against tides and storms.

This general scheme was carried out with frequent adjustments in plans in order to meet the conditions. It was a battle between men and the forces of nature. When one attack failed, new tactics were employed and finally the job was done. The first operation in the field was the excavation of the rock at the pier site until there was a bowl-shaped hole about the size of a football field, with sloping rock sides varying in height from 25 to 45 feet, and with the bottom at an average depth of 100 feet below the surface of the water. Within this bowl the circumferential fender wall was built. The lower course of the wall projected toward the inside of the bowl so as to interlock with the central portion. Thus the pier and fender are united into a solid mass from the bottom up to a point 35 feet below the water surface. Above that point, the fender wall rises as an independent structure so that it alone must withstand any blows directed against it. Two years of struggle brought completion of this pier. Meantime the corresponding pier on the Marin side had been completed and the steel tower erected upon it. Anchorages had also been completed in readiness for cable construction which had to await completion of the San Francisco tower. This required another 6 months, but in the meantime the contractor for the cables was getting everything in readiness so that there would be no delay after the tower was ready. At each anchorage he set up machinery for unreeling the wire of which the cables would be built. This wire was manufactured at Trenton, N. J. It was shipped in coils of about 4,000 feet (400 pounds) each. These coils were put onto reels at the "reeling plant." Each reel held 40 coils all spliced together into one continuous wire 160,000 feet long. Splices were made by pressing an alloy steel sleeve onto the two ends which were to be joined, the ends having first been placed in an hydraulic press which made them oval in cross section and left deep corrugations in their surfaces. These splices were so good that in most tests the wire broke outside the splice.

Before cable wire could be erected it was necessary to build "catwalks" upon which the workmen could stand. These catwalks were 16 feet wide and reached from anchorage to anchorage passing up over the intervening towers and following the curve which the cables would take, but located so that they would lie about 3 feet below them at all points. The catwalks were simply board walks carried by 12 wire ropes 1 3/16 inches in diameter and spaced 18 inches apart. These wire ropes between towers were erected by fastening one end at the base of one tower and then laying the rope along the bottom of the Gate to the other tower. It was then hoisted into position and fastened at the tower tops. Adjustment was provided in the attachment of the ropes so they could be lengthened or shortened as required to suit the sag of the cables which, of course, varied as the weight of the suspended structure was applied. The wood floor of the catwalks was painted with fire-resistant paint so as to minimize the danger of fire. At intervals of 100 feet a 12-foot section was applied to a steel frame so that it could be quickly removed to form a fire stop.

Essentially the "spinning" of the cables consists of taking bights of cable wire from the reels at one anchorage and pulling them across to the opposite anchorage where they are looped over a shoe which in turn is fastened to the anchorage. Each shoe (called "strand-shoe") is capable of holding all the wires that go to make up one strand.

The 61 strands that make a cable average 452 wires each. The spinning wheel assemblies which shuttled back and forth consisted of four sheaves, three of which always carried a bight of wire; thus six wires were laid at each passage. The spinning wheels were attached to endless hauling ropes by means of which they were pulled along their course at the rate of over 600 feet per minute. Four such spinning units were always in operation simultaneously spinning on four strands at one time. Many days saw 1,000 miles of wire placed in 8 hours of working time. The four strands during spinning were supported in temporary position above and a little to one side of the cable. As each set of four strands was completed, they were lifted one by one from their spinning positions and placed in their final positions in the cable, pinned in place at the anchorages, and then adjusted accurately to length by taking up or letting out at the strand shoe where special means for adjustment was provided.

When all strands were completed the cables were compacted by means of a machine which encircled the cable and by hydraulic pressure of 4,500 pounds per square inch squeezed it into a circular cross-section 36½ inches in diameter. Under this pressure narrow steel bands were applied about 3 feet apart to bind the cable together until the wrapping could be applied. Finally, the cable is closely wrapped with steel wire which holds it compact, and protects it against both mechanical injury and the weather.

During the year required for construction of the cables, the steel work for the suspended structure or bridge floor was fabricated and delivered. This steel work was erected by means of traveling derricks, two of which started from each tower, one working toward the shore and the other toward midspan. These travelers simply attached the steel to the suspenders which hang from the cables at 50 feet intervals. They thus proceeded, laying their own track ahead of themselves. The two main span travelers met at midspan and then each started back toward the towers setting the handrailing, curbs, and the remainder of the floor members, leaving behind them a completed steel structure ready to receive the paving. Meantime, the other two travelers from the shore ends also worked back to the towers, completing erection of the side spans. Addition of the concrete pavement to the structure completed it, ready for traffic.

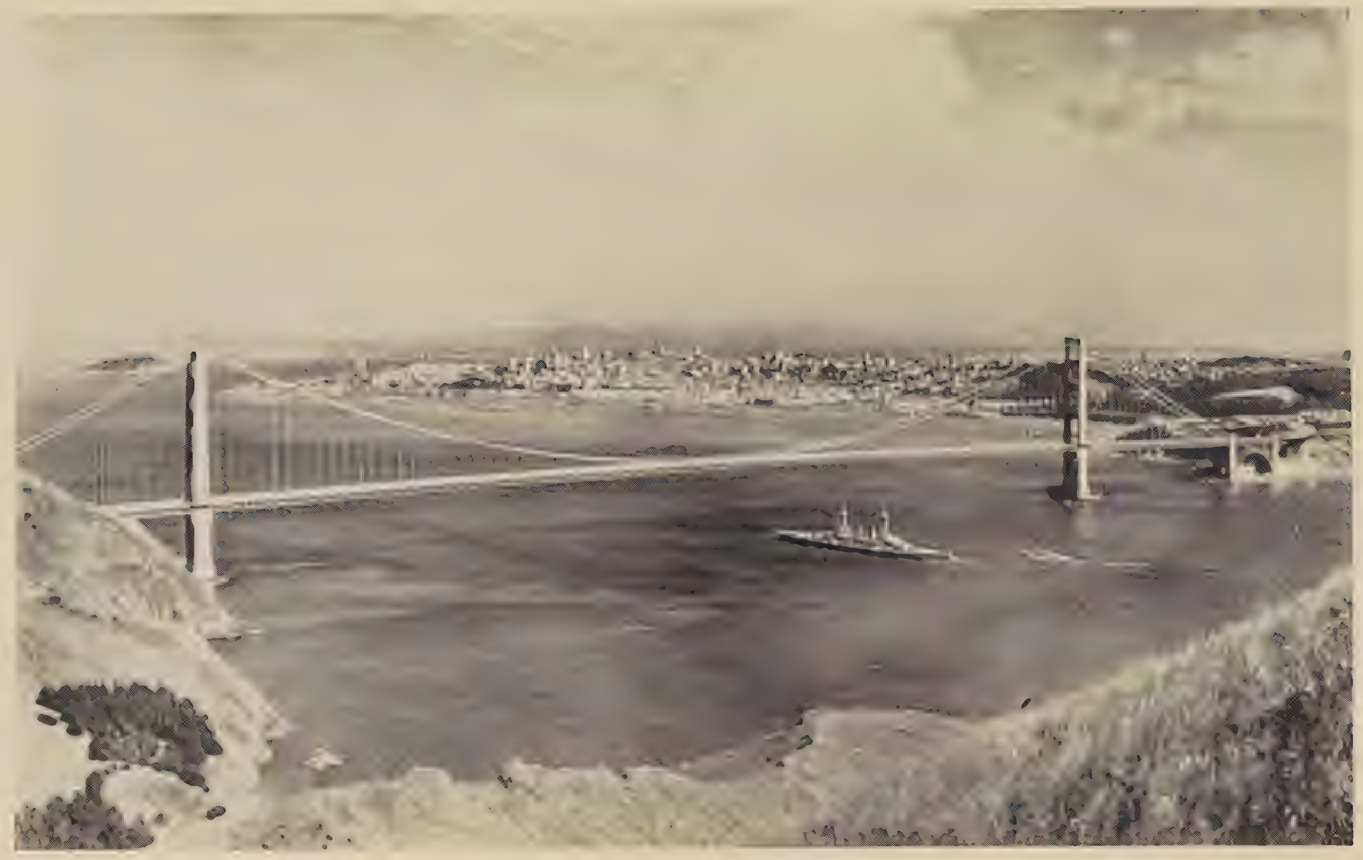
The engineers on the Golden Gate Bridge were especially concerned about the safety of the workmen on the job. According to all precedent it was feared that anywhere from 6 to 12 men would be killed in the erection of the structure. The very thought that the execution of work called for by your plans may involve such a toll of lives gives you a mighty uncomfortable feeling. Any conceivable safeguard which would reduce the hazard must be earnestly considered. Many simple, helpful measures were taken, and the result of these ordinary precautions is reflected in the low accident record. After a careful study, the engineers decided upon a safety measure that had never been applied on any other job. They concluded that as the suspended structure was built out from the towers, huge nets should be stretched across beneath and suspended from this steel work. It would be possible so to devise this that even the workmen at the extreme forward part of the work would be protected by a net carried on a framework cantilevered out ahead of the traveler. The net would extend for the full width of the bridge and 10 feet beyond on each side. Upon completion of the floor erection there would be suspended from it a continuous net 110 feet wide and 6,500 feet long, which, like a safety net in a circus, would catch men who lost their footing and save them from a drop of 250 feet into the sea and certain death. The cost of this net, its erection, and subsequent removal would be about $130,000. The engineers said this was not too much to pay for the lives of the men who would be saved. They asked the Bridge District to contribute $82,000 and the contractor the balance. The District immediately appropriated its share and then the contractor agreed to go along. Likewise the California State Industrial Accident Commission was won over to this novel safety scheme. The engineers now have the satisfaction of knowing that their insistence on the adoption of this safety net has resulted in saving the lives of 19 men.

In 5 consecutive working days, six men were caught by the net. They came up smiling and went right back to work. Ask these men and their families whether or not this $130,000 has been well spent.

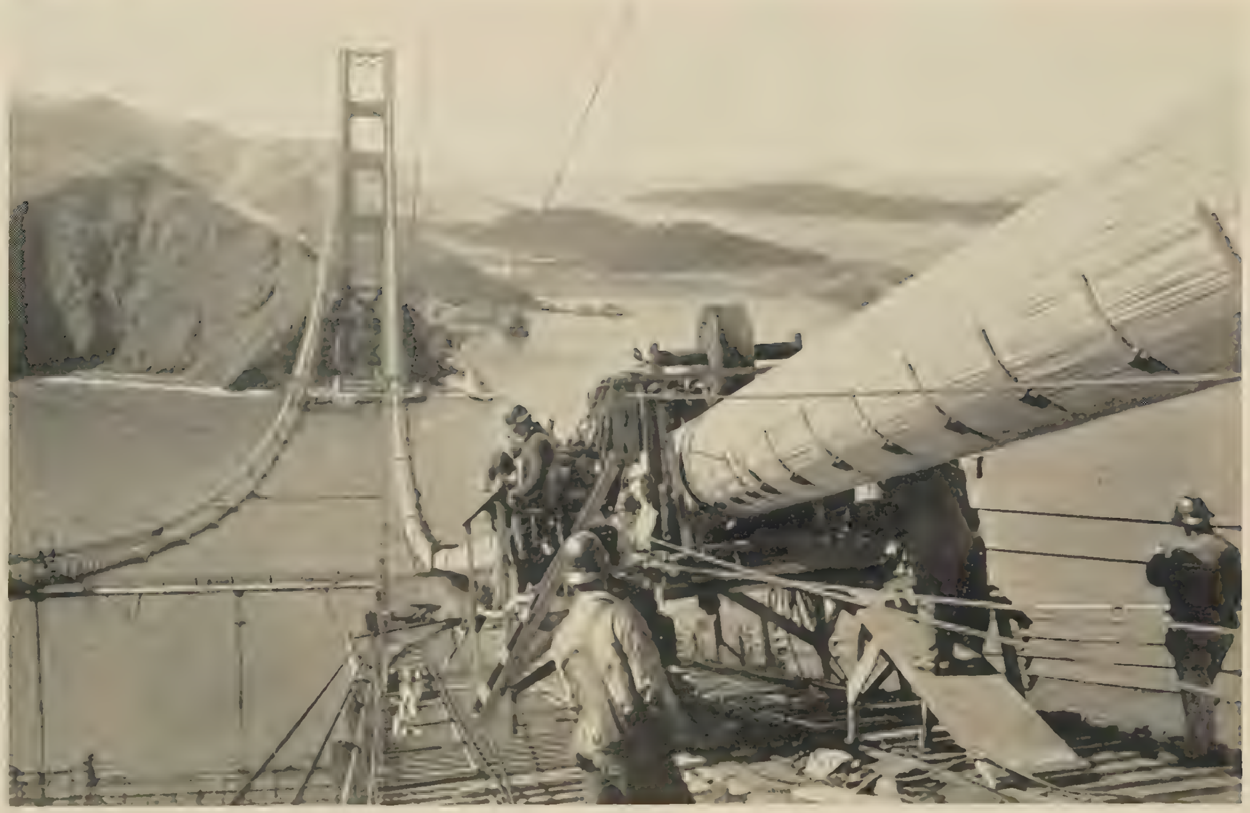
It will be of interest to note the quantities of principal materials required for the main structure only. They are as follows:

Concrete	cubic yards	300, 000
Structural steel	tons	75, 000
Cable steel and suspenders	do	25, 000
Paint	gallons	50, 000
Cement	barrels	450, 000

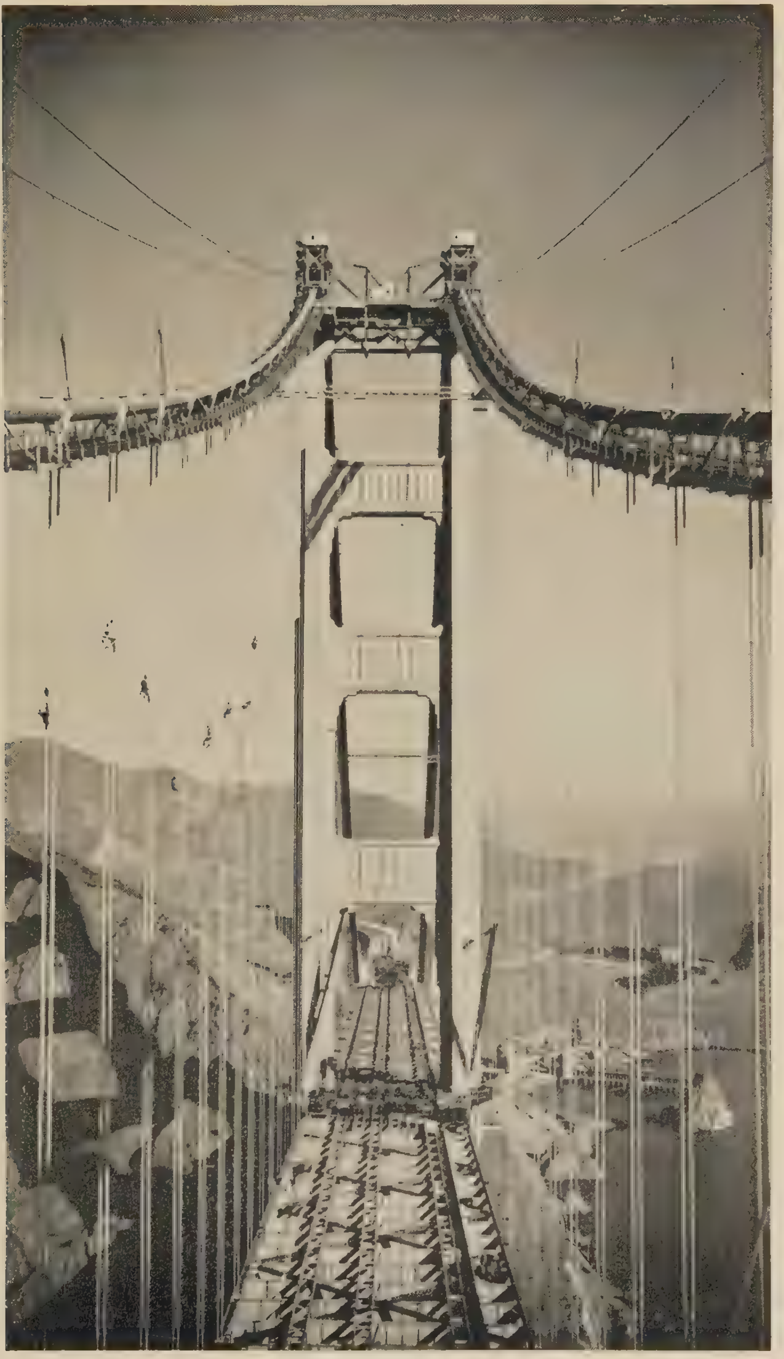
The bridge was completed ready for traffic on May 27, 1937.



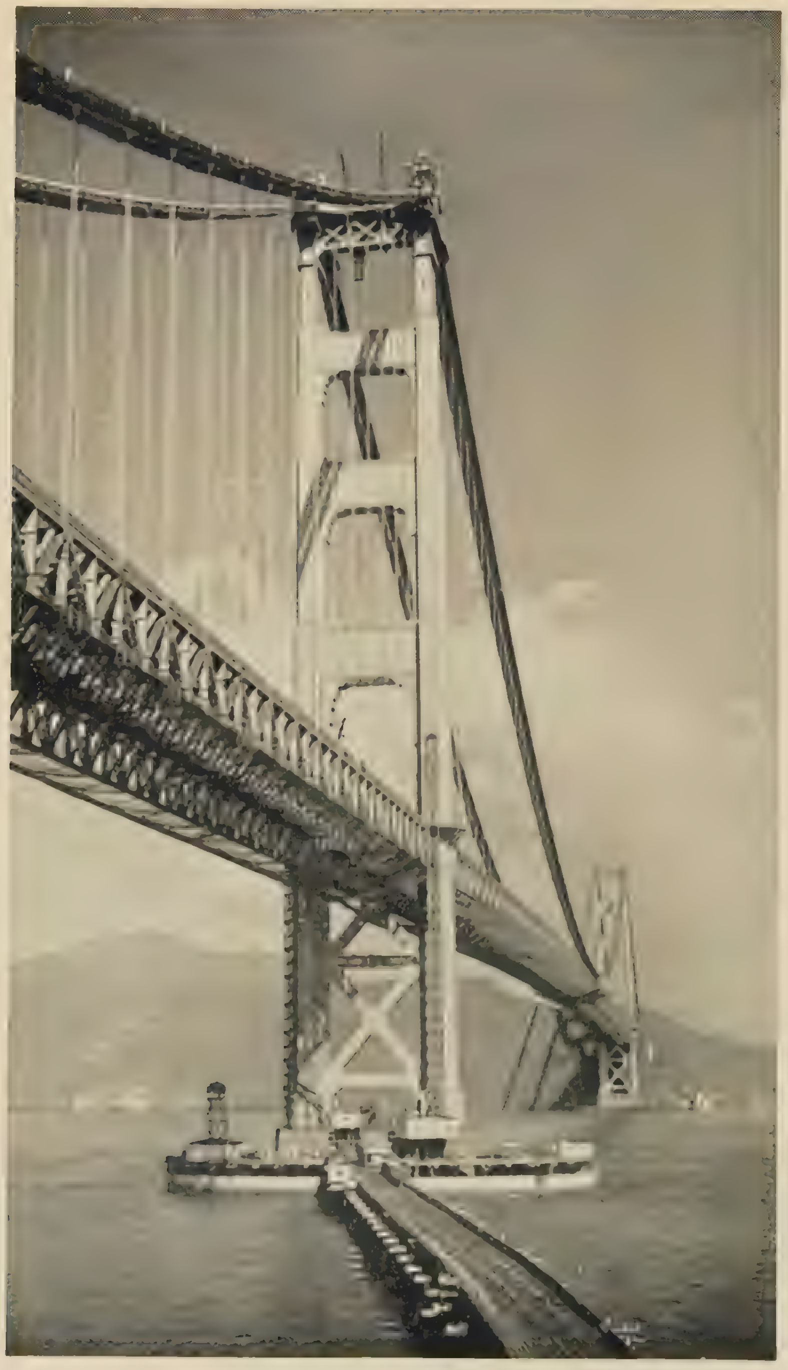
THE GOLDEN GATE BRIDGE AT SAN FRANCISCO.



COMPACTING THE CABLES.



SUSPENDED FROM THE CABLES IS THE STEEL FLOOR STRUCTURE UPON WHICH THE CONCRETE ROADWAY WAS LAID



THE SAFETY NET STRETCHED BENEATH THE SUSPENDED STRUCTURE WAS REMOVED AFTER COMPLETION OF ALL WORK.

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